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THE MONTANA ENERGY MODEL: REPORT AND SUMMARY

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THE MONTANA ENERGY MODEL: REPORT AND SUMMARY

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DRAFT REPORT

Prepared by

Socioeconomic Division
The Montana Energy and MHD Research and Development Institute
P.O. Box 3809
Butte, Montana 59701

March 1979

Prepared for

Old West Regional Commission
Under Contract No. 10771218

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- Brinker, W. F., *Oil and Gas Supply In Montana--1970 to 2000 A.D.*, October 1977;
- Gaudin, Robert, *Energy Use In Montana*, July 1978;
- Kimbal, James, *Analysis of Electric Load and Supply in Montana for Energy Modeling*, May 1978;
- Kuntz, Gail, *Coal Supply Sources of Existing and Planned Electric Power Facilities* (Map), June 1978; *Existing Hydroelectric Facilities* (Preliminary Report), May 1978; *Final Report of Western Coal Demand Research Project*, January 1978; *Montana's Natural Gas Supply*, May 1978; *Transmission Line Carrying Capacities* (Preliminary Report), May 1978;
- Rockler, Elliot, *A Report on the Oil Supply Situation In Montana*, March 1978;
- Western Analysis Corporation, *Montana Economic/Demographic Projections*, February 1978; and
- Wheeling, Terry, *Electric Utility Coal Demand Scenarios for the Montana Energy Model*, June 1978.

We would also like to express our appreciation for the cooperation of the state agencies and private industries which contributed information to this report. These include, but are not limited to, the Montana Department of Natural Resources and Conservation, Montana Power Company, Montana-Dakota Utilities Company, and Northern Natural Gas Company.

THE MONTANA ENERGY MODEL: REPORT AND SUMMARY

I. INTRODUCTION

During the 1970's, the role of energy in a modern economy has been brought into focus. This awareness can be attributed to several factors, but perhaps the most visible was the Arab Oil Embargo of 1973; this action was the turning point responsible for focusing public attention on energy needs. To say that the embargo was the single major factor in generating energy awareness, however, would be fallacious. The 1970's ushered in a new public philosophy on the environment, both social and physical, which questioned the uses and sources of energy. As this philosophy developed, concerned citizens, policy makers, and energy planners began to ask the traditional economic questions:

- Who is going to require this energy?
- How much energy is required?
- What kind of energy is needed?
- For what purpose will the energy be used?
- For how long will the energy be required?

These questions have become increasingly important to states such as Montana, which are comparatively undeveloped industrially and relatively wealthy in terms of energy sources. When this unique position is coupled with the environmental philosophies which are developing in the state and the nation, it is important that an inventory of resources be performed and probable demands for those resources be determined. Once this information is known, the economic questions can be addressed meaningfully.

The goals of this model development program, therefore, are to inventory the current supplies and demands for energy resources in Montana and to project future supply/demand scenarios. This model uses the period of 1975 through the year 2000 as its time frame.

The modeling process which was developed consisted of four phases: 1) Phase I identified the main users of energy in Montana and the interrelationship of these users; 2) Phase II identified the needs of each of the users, by energy source, through modeling the production functions of each user group identified in Phase I; 3) Phase III identified the current and probable reserves and supplies of energy resources which may be consumed by the prospective users; and 4) Phase IV simulated the probable demands on and supplies of each energy source for the prediction of the effects of any shortages.

Phase IV delineated and constructed a mathematically oriented model for use in a simulation exercise. A model is a simplified analytical framework, or skeletal representation of a complex problem, to help determine possible solutions to the problem. Mathematical models have some advantages over other models:

- Once the primary factors and interrelationships have been defined, attention can be focused on these factors alone;
- A great body of logic has been developed in mathematics for use in rational decision-making; and
- The analyst is forced to make all assumptions explicit at each step of the modeling process.

The primary modeling technique used in the Montana Energy Model is activities analysis. This technique allows the researcher to mathematically relate changes in energy demands, employment, and demography to changes in the output levels of industries in the basic sector. (The composition of the basic and other sectors is given in Appendix A, Section II.)

Activity analysis models are static equilibrium models. Equilibrium for a specified model is a condition which is characterized by a lack of a tendency to change. This equilibrium will tend to pertetuate itself, barring any changes in the external forces which govern the model.

The external forces which influence the behavior of the model are the major points of emphasis in the Montana Energy Model. Those factors which can be modeled readily were included directly, but those factors not amenable to mathematical modeling (e.g., foreign import/export restrictions) were analyzed within each of the energy-producing sectors.

The emphasis of the model on external factors, which influence the supply/demand profile, accentuates supply because of the open nature of Montana's economy. The demand for energy products is a derived demand dependent on the demand for products produced in Montana. The demand for the major products produced in Montana is dependent not only on the national economy, but the world economy and world prices for those goods produced in Montana (e.g., agricultural products, lumber, and copper).

II. THE MODEL

The theoretical framework of the Montana Energy Model is composed of eight interfacing components and six modifying parameters. A graphical view of the components and their interactions with the parameters and other components of the model is presented in the attached figure.

A. The Components of the Montana Energy Model

The eight interfacing components defined for the Montana Energy Model are economic activity, employment, energy demand, energy supply, population, work force, unemployment, and migration. These components are representative of the various segments of Montana's economy.

The six modifying parameters are productivity, growth, shortage, price, labor force participation rate, and the national unemployment rate. Modifying parameters enable the model to simulate changes on the sector influenced.

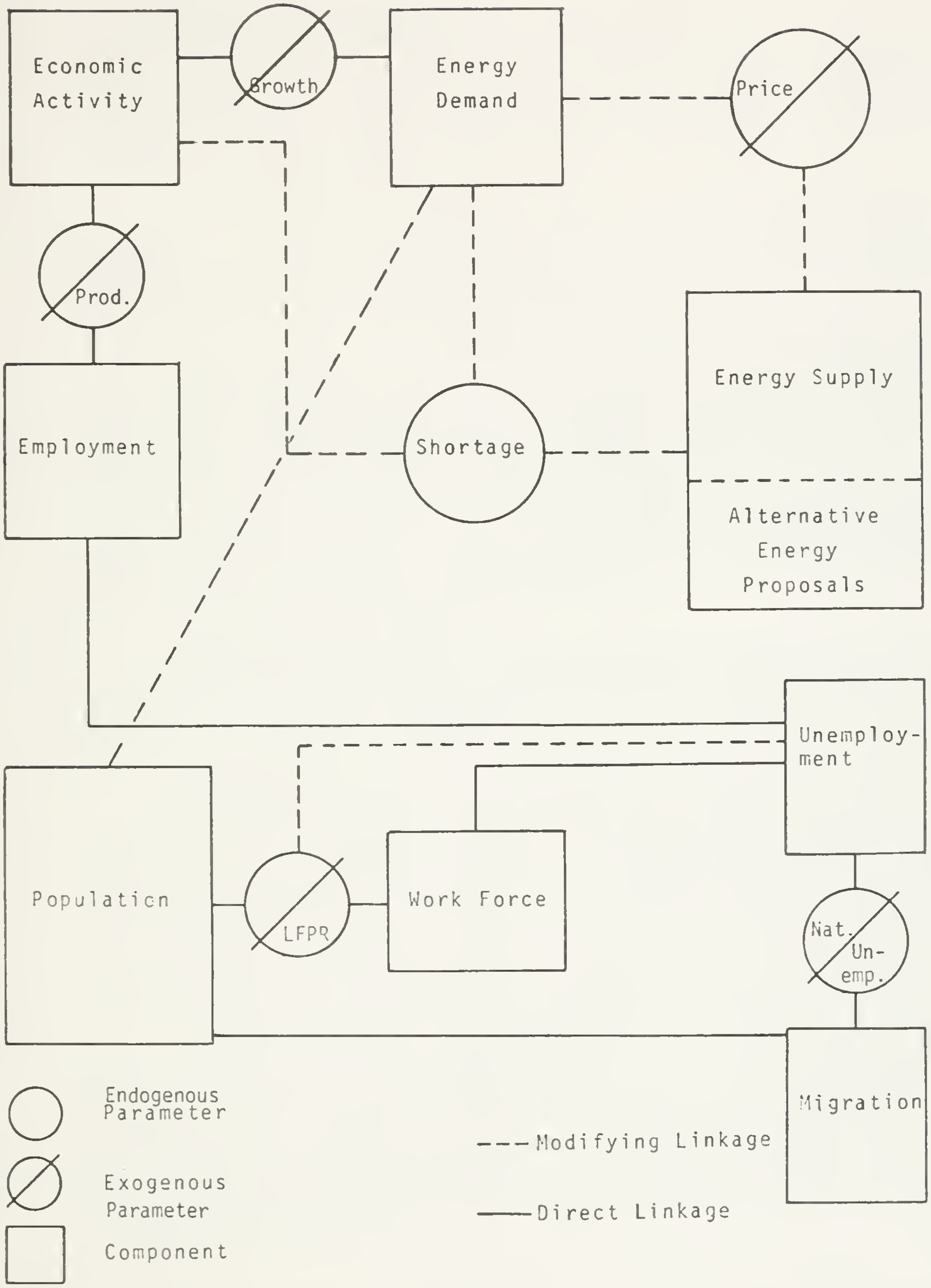
1. The Economic Activities Component

The economic activities component is the driving component of the Montana Energy Model; energy demands and employment are functionally dependent on the economic activities component. As activity (output) increases in a given sector (basic, commercial, or residential), the demand for energy of a given type increases proportionately. This increased activity also creates new employment, which in turn requires more energy. The economic activity component is modified by the growth parameter; in this manner, individual industries in the basic sector are able to grow at different rates and the effects of a change in activity in a given industry on the economy of the state can be assessed.

2. The Employment Component

The employment component is postulated to be a derived demand for labor based on the level of output in the economic activities component. The employment component consists of two sectors, the basic (goods-producing) and the commercial (service-producing). The commercial sector is defined to be a function of employment in the basic sector. This relationship is readily shown by example: as basic sector employment increases, the demand for commercial sector services such as doctors, lawyers, and mechanics, etc. increases. The employment component is modified by the parameter productivity; this parameter allows the model to assess the effects of a change in the productivity of workers in a given industry.

Overall Structure of the Montana Energy Model



3. The Energy Demand Component

The energy demand component measures the flow of energy products of a given type required to sustain the activity specified by the economic activities component. This component also measures the flow of energy products required to sustain the derived levels of activity in the commercial and residential sectors.

The energy demand component is modified by the price and shortage parameters. The price parameter is an adjustment for inter-fuel substitution and conservation effects caused by increases in the relative costs of fuels, particularly fuels used for process heat. This inter-fuel substitution is clearly evident in the state's industrial producers. For example, the major cement producers recently have switched from natural gas to coal as a source of process heat, primarily because of the relative price differentials. The shortage parameter places an absolute value on the level of energy of a given type which is available at any given point in time. This parameter causes both an adjustment in the demand coefficients and the level of possible economic activity.

4. The Energy Supply Component

The energy supply component is an inventory of the current stock of reserves available for consumption in a given time period. This component determines the shortage parameter.

5. The Population, Work Force, Unemployment, and Migration Components

The population component is closely linked to the work force, unemployment, and migration components. The population component supplies the derived demand for labor created by the economic activities component. It also determines the energy demands of the residential sector. When modified by the labor force participation rate parameter, the population estimate ultimately determines the size and composition of the work force.

When the work force is compared with the load of employment generated by the economic activities and employment components, the unemployment component can be estimated. The unemployment component is compared in turn to the national unemployment parameter to estimate the migration component. The migration level then determines the composition of the population in the subsequent time period.

B. The Simulation Model--A Modular Approach

For purposes of constructing a computer simulation model, the components and parameters discussed in the preceding section can be grouped into three working modules: 1) an energy demand module consisting of the economic activity, energy demand, and employment components and their respective modifying parameters; 2) supply module submodels which assess the supplies of energy and the source of those supplies; and 3) a demographic module which assesses the population, work force, unemployment, and migration components with their respective modifying parameters.

1. The Demand Module

The demand module computes the desired level of output in a given industry ($OUTPUT_i$) at any point in time (t) by modifying the output in the previous time period (t-1) with the exogenously determined parameter, growth:

$$OUTPUT_{i,t} = (OUTPUT_{i,\ t-1})\ (GROWTH_i) \qquad \text{(Eq. 1)}$$

Once the desired level of output in each of the basic subsectors has been computed, the demand module computes the level of employment necessary to sustain that production level. This is accomplished through the use of fixed output to employment ratios (OUTEMP). These ratios can be modified by the exogenous parameter, productivity (PROD). Therefore, employment in a given subsector (ESS_i) is defined in the following way:

$$ESS_i = (OUTPUT_i)/(OUTEMP_i)\ (PROD_i) \qquad \text{(Eq. 2)}$$

Employment in the derivative or commercial sector (COMEMP) is defined as a function of basic sector employment. This is estimated by the model as a multiplier relationship dependent on population levels, productivity, and basic sector employment levels. Once the level of employment in the commercial sector is calculated, it is allocated among the respective subsectors by using fixed-employment share percentages.

The demand module estimates the quantity of a given type of energy demanded on the basis of output in the basic sector, employment in the commercial sector, and population levels in the residential sector. Energy use coefficients are estimated for each of the basic and commercial

sectors by dividing the total amount of a given source of energy by the level of output or employment in that sector. Energy use coefficients for the residential sector are based on previous studies of that sector's energy consumption.

2. The Supply Module

The supply module consists of four separate submodels: coal, oil, natural gas, and electricity.

a. The Coal Submodel

The coal submodel assumes supply will be equal to demand over the time frame of the model. Working with this assumption, three demand scenarios for Montana coal are developed, each scenario being predicated on a different set of environmental legislation (particularly sulfur emission standards) and transportation costs. Probable users of Montana coal are identified in each of the scenarios.

b. The Oil Submodel

The oil submodel focuses its attention on the supply and distribution of crude oil products in Montana. Specific attention is placed on the Canadian import restrictions and the probable effects of their curtailment.

The oil supply submodel consists of two linked components: an oil discoveries submodel and an allocation submodel. The allocation submodel is included to compensate for the distribution system's inability to deliver the bulk of Montana crude to Montana refineries. The allocation procedure utilized is simple: a five-year moving average of the percentage of production available for Montana refineries is computed and applied to anticipated production.

The approach taken with the crude oil discovery submodel is predicated on three behavioral assumptions:

- Investment in exploratory drilling is a function of the anticipated return on that activity (e.g., higher oil prices stimulate exploration);
- The productivity of each successive dollar spent on drilling decreases as the finite amount of undiscovered oil reserves decreases (i.e., the probability of success decreases with respect to the amount of oil discovered); and

- Major discoveries of oil will encourage additional exploration because of the increased knowledge gained through that effort and also because of the increased psychological incentives which result from a major discovery.

Each of these behavioral characteristics is demonstrated to some degree in the historical data (e.g., the Bell Creek discovery of 1967). Recent increases in the world price of oil also have encouraged additional drilling and drilling expenditures.

c. The Natural Gas Supply Submodel

The natural gas supply submodel examines the current and probable future sources of supply and reserves for each of the three major producers of natural gas in Montana. These producers are the Montana Power Company (MPC), Northern Natural Gas Company (NNG), and the Montana-Dakota Utilities Company (MDU). The natural gas submodel also examines the distribution system, prices, and regulatory constraints in the natural gas industry.

Five probable sources for future natural gas supplies are evaluated. These sources are Montana, Wyoming, Canada, the Arctic, and coal gasification. Using the information compiled about each source, a mathematical model was developed which minimizes the cost to the consumer. This model considers the following points:

- Declining industrial demands caused by higher prices and uncertain supply;
- Institutional constraints placed on production in the form of production quotas and take-or-pay contracts;
- Large number of potential supply points, each subject to a different probability of success and a different price per thousand Btu's of gas delivered;
- Physical resource limitations associated with given supply points;
- Potential for changes in end-use efficiencies; and
- Random peak loads which never can be eliminated totally.

The Montana Energy Model uses a linear programming algorithm with explicit compensation for the probalistic nature of gas production and supply. Linear programming techniques are used for

optimizing an objective function subject to mathematical side conditions or constraints.

Four basic types of constraints can be identified in the linear program. These are supply, capacity, demand, and peaking (or balance) equations. Supply equations constrain the program to remain within the physical constraint of each resource. Capacity equations compensate for the institutional constraints associated with each field; these constraints may set either upper or lower boundaries on the supply of gas from any given resource. Demand equations allow the model to compensate for changes in efficiency, industrial consumption, etc. Peaking and balance equations force the system to maintain an available reserve to compensate for the random nature of peak loads.

d. The Electrical Supply Submodel

The electrical supply submodel examines the current productive capacities of each of the major producers/distributors of electrical power in the state. Specific attention is placed on the commitment of federally produced power. Existing and planned thermal and hydroelectric facilities are examined with respect to ownership and load commitments. The load structure of the state also is examined closely.

Given the supply and load configurations existing within the state, the modeling procedure used for electrical power in the Montana Energy Model follows:

- To model only utility type loads (both industrial and non-industrial) and assume the increases in these loads subject to the variables in the energy demand submodel;
- To assume all increased electrical generation to be coal-fired thermal facilities of 250 megawatt capacity, and base-loaded for production;
- To assume peak generation loads to be 55 percent of the annual generation; and
- To add the aluminum reduction load into the total load for the period 1978 to 1987 in order that the employment and demographic models can assess the impacts of aluminum production

in Montana; after the year 1987 the aluminum load is not considered.

The last parameter appears reasonable in the face of rapidly increasing transportation costs and changes in the reduction process working together to reduce the economic advantage of cheap electricity presently available in Montana. The Anaconda Aluminum contract with the Bonneville Power Administration (BPA) also ends in 1987 and current estimates indicate that all BPA resources will be committed elsewhere at that time.

The algorithm used for the mathematical modeling of electrical supplies is a linear programming method. Linear programming is a mathematical technique where an objective function is minimized or maximized, subject to a number of constraint equations.

There are four basic types of constraint equations in the electrical supply model. They are supply, capacity, demand, and peaking and balance equations:

- Supply equations limit the amount of any given resource which may be used at a given point in time.
- Capacity equations limit the generating capacity of certain types of plants. This is of particular importance to hydroelectric facilities where there is a finite number of potential sites for hydroelectric production. Coefficients in the capacity equation depend upon load factors and plant factors. Load factors represent demand duration. The load factor is a ratio of peak demand to total demand for the respective facility. The plant factor is defined similarly as the service stream available from a given facility. At best, no facility can produce at a factor exceeding unity, but in reality there are maintenance requirements, both scheduled and unscheduled, which reduce the plant availability to some lesser quantity. The electrical supply submodel allows a maximum plant factor of 0.8 production in Montana. This is representative of the history of production in Montana.
- Demand equations address the efficiency at which the electricity is converted to final demand. For example, there are efficiencies to be considered in the transmission of electrical power

from the point of generation to the ultimate user. Demand equations also can be used to simulate changes in consumption technology.

- Peaking and balance equations are necessary when attempting to model the electrical component of the model. Peak demands are random and cannot be entirely eliminated even with greatly improved load scheduling. The peak equation forces the model to generate at least a portion of peak load with devices specifically designed for peaking power production (e.g., fuel cells, gas turbines, etc.). These peaking facilities will have a load factor of about 0.1. Balance equations maintain an optimal mix between facilities designed for base loads, intermediate loads, and peaking device loads.

3. The Demographic Module

The demographic module of the Montana Energy Model has one primary goal: the projection of population levels in any given year. The projection is used to estimate the work force, net migration, and the energy demands of the residential sector.

The module utilizes a cohort-survival technique in order to estimate the number of births and the age distribution of the population, and subsequently, the size of the work force. Cohort-survival models are based on the observation that each age group (cohort) has different survival and fertility rates. Thus, as the age distribution of the population changes, the number of births and deaths will change accordingly.

The demographic submodel has two unique features not usually found with cohort-survival models: 1) an estimate of the work force, and 2) a migration component based on the level of employment. The work force estimation is computed through applying labor force participation rates to each cohort.

The migration component computes the net migration on the basis of differences in employment in the state, as opposed to the nation. This method makes the implicit assumption that the labor force will migrate to find work. For example, if state unemployment exceeds national unemployment, there will be a net out-migration. The level of state employment is endogenous to the energy model (in the employment submodel), and the level of national unemployment is set at six percent, the stated policy goal of the current administration.

III. BASELINE ESTIMATE

The Montana Energy Model has been run under a number of input conditions. The baseline case allows for a one percent annual growth in all industries except coal mining. Coal mining increases at four percent (see Appendix A, Section IV, for assumption).

A. Coal Demand and Supply

Baseline demands for coal indicate that coal extraction will increase from approximately 26 million tons in 1976 to nearly 70 million tons per year in the year 2000. This growth will make the coal industry the second largest industry in Montana at that time. Export trade will create nearly all the growth in coal demand. Minor intrastate growth in demand is expected as a result of increased coal-fired, thermal-electric generation and as a process heat substitute for natural gas.

B. Oil Demand and Supply

Baseline estimates for the supply and demand of crude oil products indicate a shortage of crude oil (especially condensate) in the immediate future, barring favorable changes in Canadian oil export policies. This shortage will occur even with no growth in the industry because of scheduled reductions in Canadian exports. At the present time, crude oil supply shortages are being avoided through the use of exchanges: Canadian crude to Montana in exchange for gulf coast and Arabian crude in eastern Canada. While this exchange system adds a considerable amount of long-term supply risk to Montana refineries supplies of Canadian crude oil to Montana are expected to continue on an exchange basis in the near to intermediate future. These exchanges are mutually beneficial to Montana and Canada: Canada has no means of economic transport of crude oil products to its eastern refineries and also reduces its balance of trade deficits by the exchange (as opposed to the purchase) of crude oil. Montana and other Northern Tier refineries presently do not have the abilities to process the higher sulfur gulf coast and foreign crude oils. Current proposals which may also alleviate shortages in crude oil include the proposed Kittimat and Northern Tier pipelines. These pipelines would carry Alaskan and other Arctic crude oils into the Northern Tier and midwestern states.

C. Natural Gas Demand and Supply

Baseline predictions for natural gas demands indicate a decline in natural gas demands from the current 80 billion cubic feet per year (bcf) to approximately 50 bcf in the year 2000. This reduction primarily is caused by a price response of industrial users, demonstrated by the reduction of industrial demands for natural gas of 6 bcf from 1975 to 1976. Further declines in natural gas usage in the commercial and residential sectors is due to price resistance and conservation efforts. Natural gas supplies do not appear to be critical over the time frame of the model. Recent discoveries of 10 to 20 trillion cubic feet of natural gas in Canada most probably will increase export allotments to the United States as the Canadian government tries to reduce its balance of trade deficit.

D. Electricity Supply and Demand

Baseline demands for electricity indicate a rapid conversion to baseload production of electricity using coal-fired thermal-electric facilities. The hydroelectric resources currently used for baseload compensate for peaking power. Further peak load facilities are required in addition to the hydroelectric peaking capacity. The price of electricity is expected to rise as peak loads increase. This increase in peak loads reduces the average load factor for the system, and subsequently, the average price of electricity rises. In addition to the change in the load factor, prices rise because of the use of more expensive fuels (e.g., gas turbines for peaking power production).

E. Demographic Changes

Baseline demographic predictions indicate a population of approximately 935,000 in the year 2000. Over the time period, the median age of the population increases and the fertility rate for the population declines, contributing to the relatively small growth in the population.

IV. CONCLUSION

The primary contribution of the Montana Energy Model is the ability to assess the changes in the energy demand profiles and employment effects of a change in a given sector of the economy. The model uses an engineering-oriented approach to relate outputs to energy and labor inputs. While this is a good technique for predicting the derived demands of energy sources, it does not explain the forces which cause the change in the economic activities sector. This is not a critical shortcoming of the model, but rather a recognition that the model should be used as a component of a larger, more comprehensive study of the state's economy.

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APPENDIX A

I. OVERVIEW OF THE MONTANA ENERGY MODEL

During the 1970's, the role of energy in a modern economy has been brought into focus. This awareness can be attributed to several factors, perhaps the most visible of which was the Arab Oil Embargo of 1973. This action was the turning point responsible for directing public attention to energy needs. To say that the embargo was the single major factor in generating energy awareness, however, would be fallacious. The 1970's ushered in a new public philosophy on the environment, both social and physical, which questioned the uses and sources of energy. As this philosophy developed, concerned citizens, policy makers, and energy planners began to ask the traditional economic questions:

- Who is going to require energy?
- How much energy is required?
- What kind of energy is needed?
- For what purpose will the energy be used?
- For how long will the energy be required?

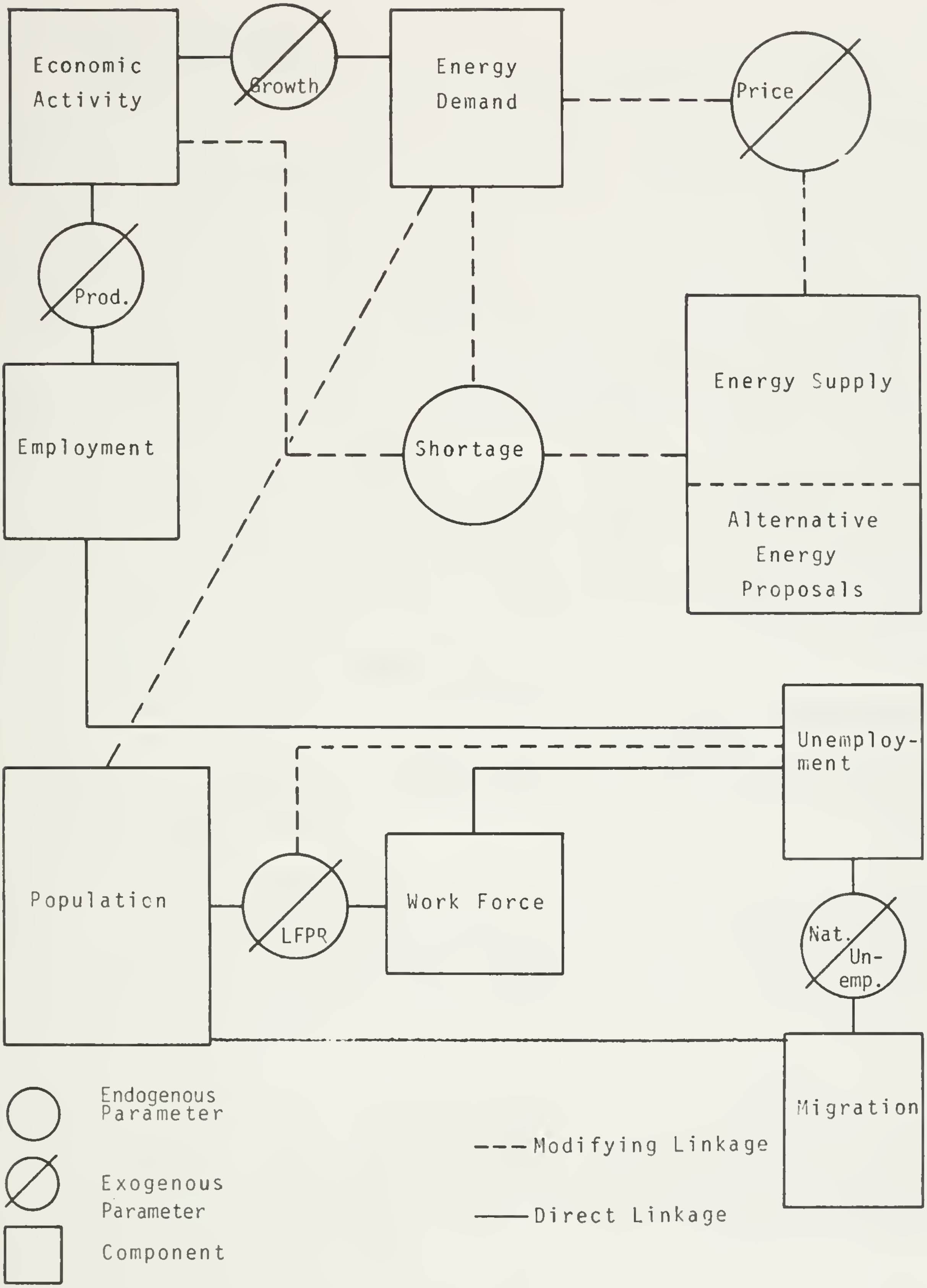
These questions have become increasingly important to states such as Montana, which are comparatively undeveloped industrially and relatively wealthy in terms of energy sources. When this unique position is coupled with the environmental philosophies developing in the state and the nation, it is important that an inventory of resources be performed and probable demands for those resources be determined. Once this information is known, the economic questions can be addressed meaningfully.

The goals of this model development program, therefore, are to inventory the current supplies and demands for energy resources in Montana and to project future supply/demand scenarios. This model uses the period of 1975 through the year 2000 as its time frame.

The approach used was to develop a model of Montana's economy from which energy demands could be estimated, the overall structure of which is shown in Figure I-1. The industrial and commercial demands for energy are based on the levels of output in their respective sectors of the economy; the residential demands for energy are based on the size of the population and subsequently

FIGURE I-1

Overall Structure of the Montana Energy Model



the number of households.

The modeling process which was developed consisted of four phases: 1) Phase I identified the main users of energy in Montana and the interrelationship of these users; 2) Phase II identified the needs of each of the users by source of energy by modeling of the production functions of each user group identified in Phase I; 3) Phase III identified the current and probable reserves and supplies of energy resources which may be consumed by the prospective users; and 4) Phase IV used a simulation exercise to test the probable demands on and supplies of each energy source and to predict the effects of any shortages.

The theoretical framework of the Montana Energy Model is composed of eight interfacing sectors and six modifying parameters. A graphical view of the sectors and their interactions with the parameters and other sectors of the model is presented in Figure I-1.

The mathematical framework of the model is developed in section VII. The mathematical formulation of each component is discussed with the respective component. The rigor associated with the mathematical formulation varies from one component to another, depending on the subject material discussed.

A. The Components of the Montana Energy Model

The eight interfacing components defined for the Montana Energy Model are economic activity, employment, energy demand, energy supply, work force, unemployment, and migration. These sectors are representative of the various segments of Montana's economy.

1. Economic Activity

Economic activity is the driving force behind the model. As economic activity increases, the demand for energy increases. Simultaneous with the increased activity is an increase in the demand for labor; hence, employment increases.

2. Employment

Employment is a derived demand for labor arising from economic activity or output in a given sector of the model. Employment is disaggregated into basic and non-basic groups in order to compensate for differing employment multipliers in each sector.

3. Energy Demand

Energy demand is the flow of energy products required to sustain economic activity. This includes the flow of raw materials, such as crude oil to a refinery or coal to a thermal electric generation facility, and the flow of such energy items as gasoline and heating fuels to the residential sector.

4. Energy Supply

The energy supply is the stock of current energy reserves and anticipated future reserves.

5. Population

Population is the gross population from which the work force is drawn and represents the number of persons which require a basic energy source.

6. Work Force

The work force is the total number of persons employed or seeking employment in a given time period.

7. Unemployment

Unemployment is the difference between the work force and the level of employment needed to sustain the economic activity.

8. Migration

Migration is the net influx or outflow of persons into the population and, therefore, into the work force.

B. The Modifying Parameters of the Montana Energy Model

The six modifying parameters of the Montana Energy Model are briefly defined below. The parameters are productivity, growth, shortage, price, labor force participation rate, and the national unemployment rate. Modifying parameters enable the model to simulate changes in the components.

1. Productivity

Productivity provides the link between output and employment. The use of this parameter as a modifier rather than a constant allows

the model to compensate partially for changes in technology, labor efficiency, and capital efficiency. However, the model is not able to differentiate between the sources of the change.

2. Growth

Growth provides the model with the ability to simulate a changing economy by allowing economic growth in the individual sectors.

3. Shortage

Shortage is a parameter which will allow the model to assess the effects of a shortage in a given form of energy.

4. Price

Price is the equilibrating device between the supply and demand of energy, assuming no external constraints such as price discrimination or enforced rationing.

5. Labor Force Participation Rate

This rate is the link between the population and the work force. Changes in this parameter will allow the model to simulate a demographic change, such as changes in the median age or the entry and exit of women into the labor force.

6. National Unemployment Rate

This rate is the link to migration. If unemployment in the region is significantly different than in the United States as a whole, the labor force will tend to move in the indicated direction to seek employment.

REFERENCES FOR APPENDIX A, SECTION I

Daly, H., On Thinking About Future Energy Requirements, Department of Economics, Louisiana State University, Baton Rouge, Louisiana, 1976.

II. THE ECONOMIC ACTIVITIES SUBMODEL

The economic activities submodel is used to predict the level of output in a component (i) during a specific time period (t). The growth in economic activity in sector (i) can be attributed to a number of factors including natural growth, technological change, etc. This growth is reflected in the input parameter growth. Thus, the economic activity in sector (i) in time period (t+1) can be shown as

$$\text{Activity}_{i,t+1} = (\text{Activity}_{i,t})\ (\text{Growth}_i) \qquad \text{(Eq. II-1)}$$

The rationale behind using an input parameter to reflect growth lies in the use of the model for simulation purposes; hence, one may stimulate a particular sector (for example, coal mining) in order to assess the effects of parameter fluctuations on the economy and energy demand as a whole.

A. The Composition of the Economic Activities Component

When discussing the composition of the economic activities in any economic entity, such as a state, the primary issue is the level of disaggregation desired. The greater the level of disaggregation that is desired, the more difficult the data collection process becomes. In recognition of the virtual impossibility of a completely disaggregated data base, economists have developed an economic base theory which lumps together segments of the economy on the basis of function within the economy. Utilization of this theory greatly reduces the attendant data problem in the modeling process by making the simple assumption that the level of activity is not dependent on one particular producer's output.

B. The Composition of the Economic Subsectors

When attempting to simulate the Montana economy for purposes of developing an energy model, three primary economic operatives can be identified:

- The basic or goods-producing subsector;
- The commercial or service subsector; and
- The residential or household subsector.

1. The Basic Subsector

The basic, or goods producing, subsector is subject to the greatest variation in its composition. Various models of the Montana economy

have included different elements in this subsector, but all of the models have the following elements:

- Agriculture;
- Mining;
- Durable goods manufacturing; and
- Non-durable goods manufacturing.

Other elements which often are included in the basic subsector are contract construction, federal government employment, and rail transportation. For the purposes of this modeling effort, it was decided that these should be included in the basic sector.

The basic subsector of the Montana Energy Model is composed of the following elements and subelements. Each element is identified by a two-digit Standard Industrial Classification (SIC) number. This number is a descriptive label assigned to each industry by the U.S. Department of Commerce.

a. Agriculture

This element is composed of Standard Industrial Classification (SIC) Codes 01 through 06, which include both agricultural crops and livestock.

b. Mining

This element consists solely of SIC 12, bituminous and lignite coal mining. The other mining processes conducted in the state, for the most part, are reflected in the processing of the materials because of the vertical integration of the firms involved in mineral extraction and processing in Montana.

c. Durable Goods Manufacturing

This element is composed of producers in the following SIC categories:

- SIC 24--Lumber and woods products;
- SIC 32--Stone, clay, and glass products; and
- SIC 33--Primary metals products (this category is disaggregated into three subgroups of copper, aluminum, and other primary metals--mainly lead and zinc).

d. Non-durable Goods Manufacturing

This element contains producers from the following SIC categories:

- SIC 20--Food and kindred products;
- SIC 26--Paper and pulp products;
- SIC 27--Printing and publishing; and
- SIC 29--Petroleum products.

e. Contract Construction

This element is composed of firms in SIC Codes 15 through 17. Because of the highly complementary nature of these trades, any attempt to further disaggregate these firms would be misleading.

f. Federal Government Employment

This element consists of SIC Code 91 (Postal Service) and SIC Code 94 (Other Federal Public Administration). The inclusion of federal government employment as a basic industry is justified by the fact that nearly all federal employment is determined exogenously to the state.

g. Railroad Transportation

This subsector consists of SIC Code 40. The reason for the inclusion of the sector is that most rail traffic in Montana originates elsewhere in the nation and simply passes through the state.

2. The Commercial Subsector

The commercial or service subsector is composed of virtually all the remaining business activities which occur in the state. Enumeration of these activities on an individual basis would be problematic, if at all possible. Therefore, the model disaggregates the commercial subsector into ten groups:

- Transportation other than rail--SIC categories 47 through 49;
- Communications--SIC category 48;
- Utilities--SIC category 49;
- Wholesale trade--SIC category 50;
- Retail trade--SIC categories 52 through 59;

- Finance, insurance, real estate, service (FIRE/s)--SIC categories 60 through 67, 71 through 79, 81, 83, and 86 through 89;
- Hospitals and nursing homes--SIC category 80;
- Schools--SIC categories 82 and 84; and
- Public administration--SIC categories 92 and 93.

The model hypothesizes commercial sector activities as a function of basic sector activities. The link between the level of activity in the basic and commercial sectors is the level of employment in the basic sector. This relationship is developed in the employment submodel.

3. The Residential Subsector

The economic activities in the residential subsector are limited to the consumption of goods and services and the supply of labor. Although this may seem to be an over-simplifying assumption, it is virtually impossible to assign a value to the labor exchanged and the value added in this sector; e.g., what is the value of a housewife?

REFERENCES FOR APPENDIX A, SECTION II

Bureau of Business and Economic Research, Montana Economic Study, University of Montana, Missoula, Montana, 1970.

Department of Community Affairs, Input/Output Model, Montana Futures Project, Division of Research and Information Systems, State of Montana, Helena, Montana, 1976.

Isard, Walter, Methods of Regional Analysis, Massachusetts Institute of Technology, Cambridge, Massachusetts, 1960.

Miernyk, William, The Elements of Input-Output Analysis, Random House, New York, New York, 1967.

The Montana Energy and MHD Research and Development Institute, Montana Natural Gas Demand Study, prepared for the State of Montana and the U.S. Federal Energy Administration under Contract No. FEA-CA-05-60743-00, December, 1976.

III. THE EMPLOYMENT SUBMODEL

The employment submodel has a crucial role in the overall development of the Montana Energy Model. The level of employment developed by this submodel directly influences the demand for energy in the commercial sector and the level of net migration in the demographic submodel. A graphical view of the submodel is shown in Figure III-1.

The modeling process identifies two components of total employment--basic sector employment and commercial sector employment. A graphical exposition of the components, their historical interrelationships and relationship to total employment, is given in Figure III-2. Both of these sectors are subject to the modifying parameter productivity (PROD). This parameter reflects changing levels of labor productivity in the respective sectors and subsectors of the economy.*

A. Basic Sector Employment

The employment level in the basic subsector (ESS_i) is defined as a function of output levels in sector (i) and productivity in sector (i).

$ESS_i = f\ (OUTPUT_i,\ PROD_i)$, where (Eq. III-1)

i = an element index

f = symbolic of a functional relationship,

OUTPUT = physical output in either dollars or units of production, and

PROD = the productivity parameter.

Total employment in the basic subsector (TE_b) can be defined as the sum of the sectors.

$TE_b = \sum_{1=1}^{n} ESS_i$, where (Eq. III-2)

n = number of subsectors, and

Σ = a sum over the range i, i = 1...n

---

*The parameter PROD reflects a change in the output per employee and does not attribute this change to either labor productivity increases or changes in the available capital stock.

Figure III-1

Employment Submodel of the Montana Energy Model

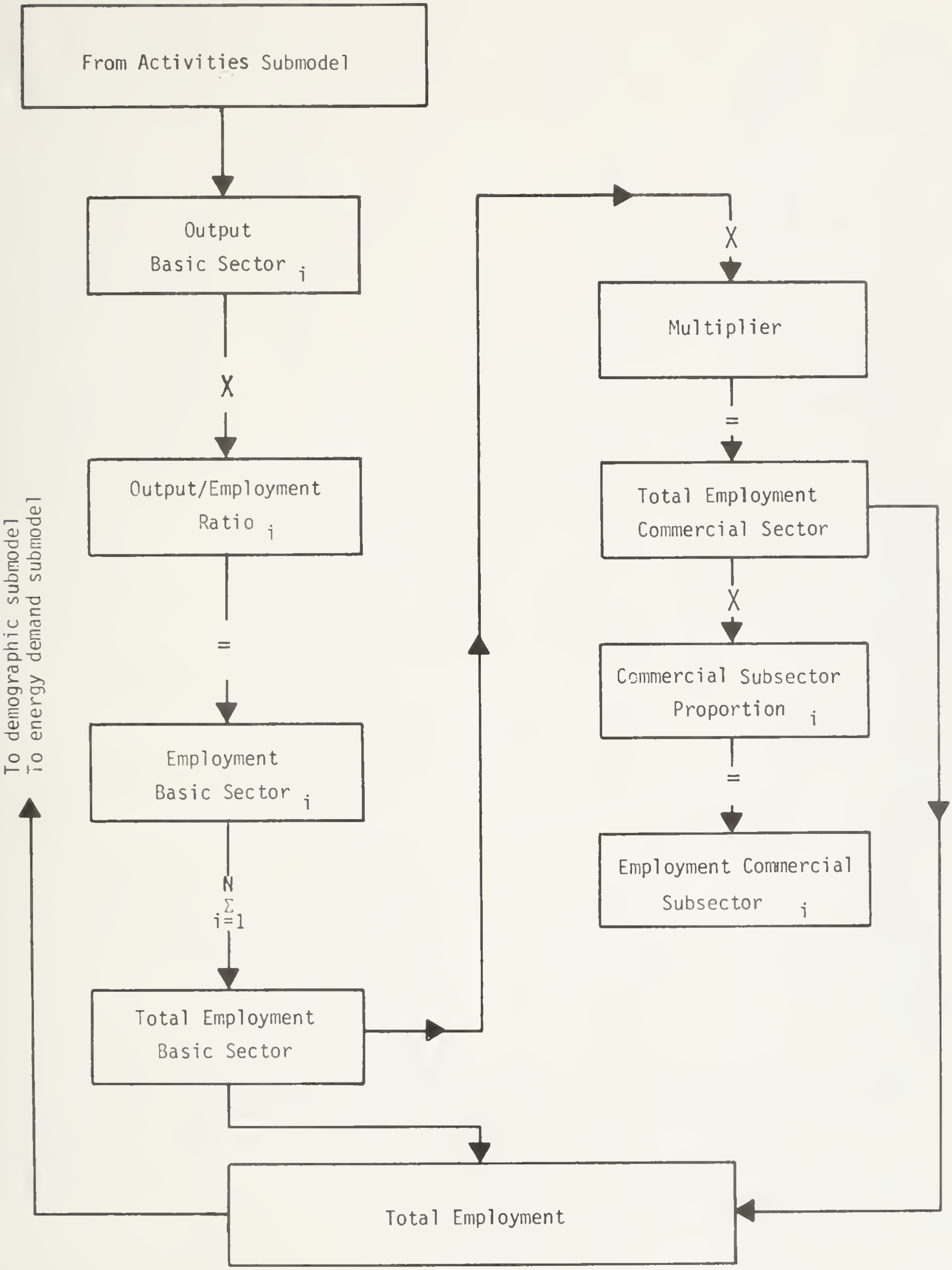
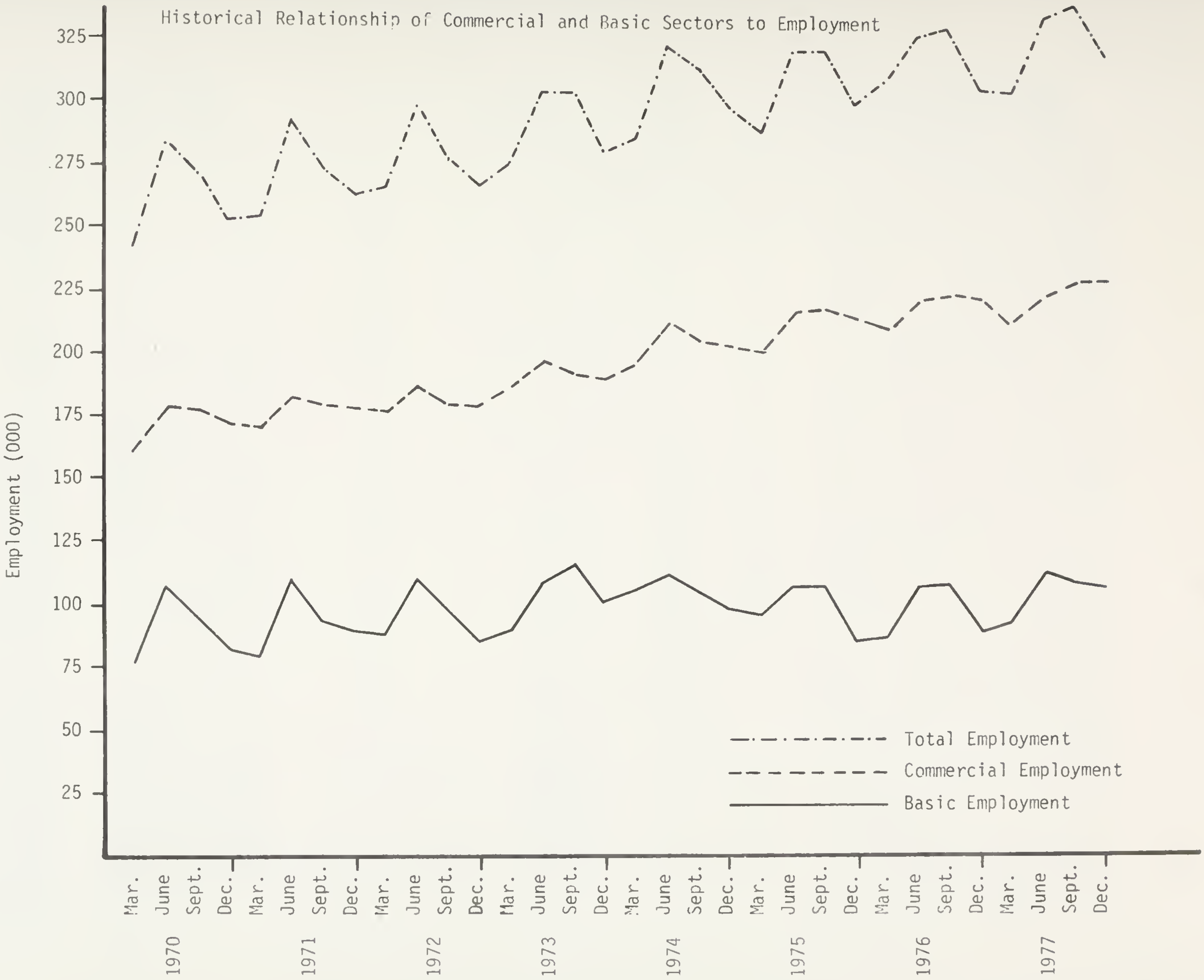

From Activities Submodel
Output Basic Sector $_i$
X
Output/Employment Ratio $_i$
=
Employment Basic Sector $_i$
$\sum_{i=1}^{N}$
Total Employment Basic Sector
X
Multiplier
=
Total Employment Commercial Sector
X
Commercial Subsector Proportion $_i$
=
Employment Commercial Subsector $_i$
Total Employment
To demographic submodel
To energy demand submodel

Figure III-2

Historical Relationship of Commercial and Basic Sectors to Employment



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In order to establish the functional relationship between the level of employment in subsector (i) and the level of output in subsector (i)*, the ratio of output to employment was calculated for each subsector, as shown in Table III-1. These ratios can be modified by the parameter PROD. The model implicitly assumes productivity to be equal to one unless explicitly given a different value. If a value greater than one is assigned to $PROD_1$, productivity per employee in subsector (i) is increased and the output/employment ratio will rise. Conversely, if PROD is less than one, the output/employment ratio will fall. As this ratio changes, the employment in subsector (i) will change.

$$ESS_i = OUTPUT_i / (OUTPUT_i/EMPLOYMENT_i)\ (PROD_i) \qquad \text{(Eq. III-3)}$$

The magnitude of the total employment in the basic sector may change, but the mode of calculation (Eq. III-2) will remain the same.

B. Commercial Sector Employment

Employment in the commercial or service sector is hypothesized to be a function of employment in the basic sector and the level of productivity in the basic sector, Equation (III-4).

$$TE_c = f\ (TE_b,\ POP_{t-1},\ PROD_b),\ \text{where} \qquad \text{(Eq. III-4)}$$

TE_c = total employment in the commercial sector, and

POP_{t-1} = population in the previous time period.

The functional relationship between commercial sector employment and employment in the basic sector is based on the concept of a multiplier; i.e., an increase in basic sector employment will create a disproportionately larger increase in the total level of employment. This increase occurs because of the requirements of the basic sector employee for services offered by the commercial

---

*Because the parameter (PROD) is a change parameter, it is equal to one for any given point and only has a value different from one when a rate of change is being measured; thus, it is legitimate to ignore this term in the function.

TABLE III-1

OUTPUT/EMPLOYEE Ratios for Basic Industries* 1976

Sector	Employees	Output **	Output/Employee (Unit)**
Agriculture	33,400	$ 996.975 x 10^6	$ 29,840
Mining	800	26,226,345 (Tons)	32,783 (Tons)
Contract Construction	13,800	$ 331.2 x 10^6	24,000
Durable Goods Manufacturing			
Lumber and Wood Products	7,200	$441.3 x 10^6	$ 61,290
Stove, Clay and Glass	1,000	$100.3 x 10^6	$100,300
Primary Metals			
Copper	4,400	180,000 (Tons)	40.90 (Tons)
Aluminum	953	146,177 (Tons)	153.38 (Tons)
Other	325	66,572 (Tons)	204.83 (Tons)
Non-Durable Goods Manufacturing			
Food	2,400	$343.6 x 10^6	$143,160
Paper and Pulp	492	404.565 (Tons)	822.28 (Tons)
Printing and Publishing	2,200	$ 64.7 x 10^6	$ 29,400
Petroleum Products	1,200	50,332,433 (bbl)	41,935.4 (bbl)
Other Basic			
Rail	6,100	$308,355	$ 50,550
Federal Government	13,700	NA	NA

---

* Whenever possible output is measured in terms of physical output units (short tons).

** Data is in 1976 dollars when applicable.

REFERENCES FOR TABLE III-1

1. State Department of Labor and Industry, Montana Employment and Labor Force, Research and Analysis Section, Employment Security Division, Helena, Montana, July 1978.

2. Personal communication with Joe Lundberg, Market and Research Analyst, Montana Department of Agriculture.

3. Personal communication with Alan Davis, Research Division, Montana Department of Revenue.

4. U.S. Department of Commerce, Annual Survey of Manufacturers, 1976, Bureau of Census, February 1978.

5. Personal communication with Bruce Thompson, Montana Public Service Commission.

sector, e.g., doctors, automotive products,* etc.

The relationship between commercial sector employment and productivity in the basic sector is defined much less clearly. Historically, it has been noted that the commercial or service subsector has grown in proportion to the basic subsector. This growth has not been explained by an increase in employment in the basic subsector but can be linked to the change in output in the basic subsector. Therefore, the level of employment in the commercial sector is influenced by both the level of employment and the productivity of the employees in the basic sector. This relationship between productivity in the basic subsector and employment in the commercial subsector is obvious as an income effect. As productivity increases in the basic subsector, wages rise. The increase in wages manifests itself in an increased demand for goods and services in the commercial sector.

These functional relationships were estimated for the model using a multiple regression technique and the estimating Equation (III-5) over a time series.**

$$\ln (TE_c) = B_0 + B_1 \ln (TE_b) + B_2 \ln (PROD), \text{ where} \qquad \text{(Eq. III-5)}$$

B_0, B_1, B_2 = estimated constants

PROD = an estimate using an index of output per employee.

(Source: Bureau of Labor Statistics, Handbook of Labor Statistics, 1977)

When Equation (IV-5) is estimated, the following equation is generated.

$$Ln (TE_c) = 11.0 + 0.1366 \ln (TE_b) - 0.045 \ln (PROD) \qquad \text{(Eq. (III-6a)}$$

or

$$TE_c = 3.737 (TE_b) \qquad \text{(Eq. (III-6b)}$$

---

* This is a well documented phenomena which has wide acceptance. However, indications are that it works at a much slower rate in work force reductions and in communities which have extensively under-utilized capital facilities.

** The regression of the natural logarithms of the respective variables allows the computation of the elasticities of the dependent variable with respect to the independent variable. The estimated value of the dependent variable then becomes

$$y = A \sum_{i=1}^{2} x^{Bi}, \text{ where } \ln (A) = B_0 .$$

Equation (III-6) is utilized by the model to estimate the total employment in the commercial sector. Once total employment in the commercial has been estimated, the problem of allocating that employment among the subsectors of commercial employment remains. This problem is overcome by the assumption that each of the subsectors maintains the same proportion of commercial sector employment. The subsectors and their respective proportions of commercial sector employment are shown in Table III-2. Although this assumption may cause a secular distortion of the allocation of employment with the sector, it is felt that in the short run it is an adequate allocation process.

TABLE III-2

Employment in the Commercial Sector*

Sector	Employment (000)	Cumulative Total (000)	% of Total
Transportation (except rail)	6.0	6.0	3.1
Communications	3.88	9.88	2.0
Utilities	3.51	13.39	1.9
Wholesale Trade	15.1	28.49	8.0
Retail Trade	48.6	77.09	25.8
FIRE/s**	43.7	120.79	23.2
Hospitals and Nursing Homes	14.9	135.69	7.94
Schools	30.0	165.69	15.98
Public Administration	22.0	187.69	11.7
TOTAL	187.69	187.69	100

* Based on 1976 employment data, "790 series".

** FIRE/s is finance, insurance, real estate, and services.

REFERENCES FOR APPENDIX A, SECTION III

Davis, Alan, personal communication, Research Division, Montana Department of Revenue, August 1978.

Federal Energy Administration, Energy and U.S. Agriculture: 1974 Data Bases, Office of Conservation, April 1977.

Isard, Walter, Methods of Regional Analysis, Massachusetts Institute of Technology, Cambridge, Massachusetts, 1960.

Kmenta, J., Elements of Econometrics, Macmillan Publishing Company, New York, New York, 1971.

Lundberg, Joe, personal communication, market and research analyst, Department of Agriculture, Helena, Montana, November 1978.

The Montana Energy and MHD Research and Development Institute, Survey Responses to Industrial Uses of Fuel Survey, Butte, Montana, June 1978.

The Montana Energy & MHD Research and Development Institute, Survey Response from a representative industry (name withheld to prevent disclosure of operations), Butte, Montana, June 1978.

Mudge, Fred, personal communication, The Anaconda Company, Louisville, Kentucky, October 1978.

State Department of Labor and Industries, Statewide Industry/Occupation Projections, 1985, Research and Analysis Section, Employment Security Division, Helena, Montana.

State Department of Labor and Industry, Montana Employment and Labor Force, Research and Analysis Section, Employment Security Division, Helena, Montana, August, 1978.

Thompson, Bruce, personal communication, Montana Public Service Commission, Helena, Montana, October 1978.

U.S. Department of Commerce, "Detailed Characteristics, Montana," 1970 Census of Population, 1970.

U.S. Department of Commerce, "General Characteristics, Montana", 1970 Census of Population, 1970.

U.S. Department of Commerce, Annual Survey of Manufacturers, 1976, Bureau of Census, February 1978.

IV. THE ENERGY SUPPLY SUBMODELS

The energy supply section of the Montana Energy Model consists of four independent submodels--one each for the major energy sources: coal, oil, natural gas, and electricity.

The supply of each resource is subject to a unique set of geographical, technological, institutional, and distributional constraints. In recognition of these constraints, the energy supply submodels have not been limited to a description of the mathematical modeling technique utilized; rather, each of the submodels attempts to describe for each energy source the unique set of constraints which influence present and future supplies of energy.

A. Coal

The magnitude of the coal deposits in Montana assures its supply for at least 50 years. The demand for coal, however, becomes a very critical question. Coal presently is one of Montana's largest exports and is expected to increase substantially over the next couple of decades. With this growth there will be an increase in the demands of the coal industry for inputs of other energy sources, labor, and services.

Because the supply of coal is so large relative to the demand for coal, the Montana Energy Model has concentrated on coal demand and the parameters which influence that demand.

1. Analysis Framework

The demand for Montana coal can be separated into four sectors for analysis:

- Out-of-state exports for electric generation;
- In-state use for electric generation;
- Industrial use; and
- Synthetic fuels (synfuel) production.

This modeling project has focused on exports for electric generation, which have comprised about 85 percent of recent demand for Montana coal. Projections of in-state, coal-fired electric generation are developed internally by the model. Industrial and synfuel demand for Montana coal is small at present (about 1.5 million tons shipped to out-of-state

industries in 1976) and is likely to remain relatively small for the near term. A detailed analysis of coal demand for industrial and synfuel use is impractical at this time because of problems in controlling the variables of these sectors.

The most thorough analysis of future coal demand from the Northern Great Plains (NGP) region was prepared in 1975 by the Montana University Coal Demand Study team. The project also concentrated on demand for coal-fired electric generation and developed a rigorous analytical framework for assessing the relative impacts of the major policy and economic variables affecting NGP coal productions. No attempt has been made here to duplicate the scope of the Coal Demand Study, but this modeling study is an attempt to verify the results of the 1975 study accounting for current policy discussions and to provide a more detailed investigation of the Montana portion of NGP coal demand.

Briefly, the Coal Demand Study developed projections of future Montana coal demand based on five primary considerations:

- The identification of the geographic market area for NGP coal based on a model driven by coal production, transportation, and pollution control costs for competing coal sources;
- The demand for electricity within the market area, based on an econometric model incorporating prices of electricity and natural gas;
- The share of electric demand to be met by coal-fired generation based on a review of hydroelectric and gas/oil power plant plans;
- The share of coal-fired plants in the market area to be supplied by NGP coal, based on available coal contract data; and
- The share of NGP coal production to be supplied from Montana, based on the 1980 contract percentage of total NGP coal supply.

For this modeling study, available state and regional forecasts of energy supply and demand were reviewed; however, these forecasts primarily reflect utility proposals for new generating capacity based on traditional growth rates in electric consumption. Consequently, this analysis has focused on a power plant-specific review of available utility projections of a new capacity and coal sources for electric utilities within the market

area for Montana coal.

2. Geographic Market Area

For this modeling study, it is convenient to identify five sub-regions within the overall geographic Montana coal market area:

- Minnesota;
- Wisconsin and Michigan;
- Illinois and Indiana;
- A Midwest/Southwest region (consisting of the states of South Dakota, Iowa, Nebraska, Kansas, Missouri, Arkansas, Oklahoma, Louisiana, and Texas); and
- The Pacific Northwest region (Idaho, Washington, and Oregon).

The total geographic area corresponds very closely with the largest market area identified in the Coal Demand Study. Table IV-1 shows the regional distribution of coal shipments from Montana in recent years, and current utility plans concerning additions of coal-fired generating capacity and use of western coal are summarized in Table IV-2.

Several observations can be made from the data presented on these two tables. Within the state of Minnesota, significant coal-fired generating capacity is planned which is expected to use Montana coal almost exclusively. Some potential exists within current utility plants for further Montana coal use within Wisconsin and Michigan. Large amounts of new coal-fired generating capacity are planned within Illinois and Indiana; however, announced plans do not anticipate additional Montana coal use in these states. While major increases in coal-fired generating capacity are projected for the Midwest region, current plans indicate that virtually all the western coal to be used is expected to be from Wyoming. This projection appears reasonable, primarily because of the transportation cost advantages of Wyoming coal shipped to this market region. (Available data indicate only one small contract for Montana coal for use within Texas, which is included in the projections below.) The Pacific Northwest, on the other hand, is planning little coal-fired generating capacity. This trend, however, is dependent on the large number of nuclear units

TABLE IV-1

Coal Shipments from Montana to Electric Utilities, 1973 to 1976*
(Million Tons)

Region	1973	1974	1975	1976
Minnesota	3.92	5.23	6.21	8.16
Wisconsin/Michigan	0.13 ***	0.99	3.22	4.13
Illinois/Indiana	5.66	6.68	10.13	10.12
Midwest/Southwest	.04 ***	0.21 ***	0.63 ***	0.23
Pacific Northwest	0.00	0.00	0.00	0.00
Montana	0.88	0.82	1.20	2.32
Total Utility Shipments	10.62	13.94	21.38	24.96
Total Montana Production **	10.73	14.12	22.16	26.18

* Source: Federal Power Commission, Form 423 Reports

** Source: Montana Department of Revenue

*** Primarily Spot Purchases

TABLE IV-2

Proposed Coal-Fired Additions and Western Coal Use, 1980 to 2000*
(Thousand Megawatts)

Region	Proposed Coal-Fired Additions			Additions Planning Montana Coal Use			Additions Planning Wyoming Coal Use			Additions Planning Unspecified Western Coal		
	1980	1985	1990	1980	1985	1990	1980	1985	1990	1980	1985	1990
1. Minnesota	0.7	2.9	3.2	0.7	2.1	0.0	0.0	0.0	0.0	0.0	0.8	3.2
2. Michigan/Wisconsin	1.0	5.1	4.2	0.0	1.4	0.0	0.9	1.2	0.0	0.0	1.4	.7
3. Illinois/Indiana	5.7	8.2	9.7	0.0	0.0	0.0	1.5	2.6	0.0	0.0	0.0	0.0
4. Midwest (excluding Texas)	9.4	15.4	5.6	0.0	0.0	0.0	7.4	8.6	2.8	0.0	1.3	0.2
5. Pacific Northwest	0.0	0.3	(1.4)**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	(1.4)**

* Source: G. Kuntz, Final Report to Montana Energy Model Project, Table XI, January 1978.

** May be proposed if a nuclear unit is not built.

proposed for the Northwest region, one of which currently is involved in litigation and which may affect plans for additional nuclear plants. Therefore, the market area for future shipments of Montana coal for electric generation, based on current utility plans, appears to consist primarily of Minnesota with smaller and more uncertain markets in the Wisconsin/Michigan and Illinois/Indiana regions. Little, if any, penetration into the Midwest/Southwest and Pacific Northwest regions is projected.

Pollution control regulations will have a significant impact on the market area for western coal. A sulfur emissions standard which allows low-sulfur western coal to be burned without flue-gas desulfurization (FGD) enables western coal to be shipped substantial distances while remaining cost-competitive. Based on the market area model developed for the Coal Demand Study, pollution control regulations were shown to be the single most important factor in determining market area. The Coal Demand Study developed two market area scenarios. The larger market applied to new power plants constructed after the implementation of the current sulfur emissions standard of 1.2 pounds of sulfur dioxide (SO_2) per million Btu's of coal consumed, and compared the use of high-sulfur Midwestern coal with FGD versus the use of low-sulfur NGP coal with no scrubbing. This market boundary passed through southern Wisconsin, western Illinois, and central Missouri. The second, smaller market area applied to existing power plants and compared the use of both Midwestern and NGP coal without FGD. This market boundary passed through central Minnesota, eastern Nebraska, and central Kansas.

New regulations expected to be finalized in 1978 likely will lower substantially the allowed sulfur emissions for new power plants. While the exact emissions level to be allowed is under debate at this time, the effect will be to require scrubbing of virtually all western coal in new power plants. Current proposals center on a scrubbing requirement of 80 to 90 percent of the coal's sulfur content, with a minimum of 0.5 to 0.6 pounds SO_2 per million Btu (essentially the highest level of emissions allowed without scrubbing), and a maximum of about 1.2 pounds SO_2 per million Btu (essentially the highest level of emissions allowed with scrubbing). Analysis performed by the Stanford Research Institute (SRI)

indicates that scrubbing costs are relatively insensitive to the sulfur content of coal, and also are relatively insensitive to the exact emissions level mandated once the requirement is sufficiently stringent to force some scrubbing of flue gases. Hence, the likely impact of these regulations will be to require FGD systems on all plants using Montana coal constructed after the effective implementation date of the new standards. This date has not yet been set, but it is expected to be in the 1980 to 1982 time-frame.

The effect of these proposed regulations would be to redefine the available markets. In the absence of new regulations on emission standards, the market would include the larger area identified by the Coal Demand Study. If the new emission standards are implemented, the smaller market area described by the Coal Demand Study is the most probable market. This smaller market area will represent the transportation advantage of western coal rather than the current low sulfur advantage that western coal enjoys.

Comparing these two market areas for NGP coal with the plant-specific utility expectations of coal supply and with transportation distances, three market area scenarios for Montana coal demand were developed as the basis for the projections presented below. The largest Montana coal market would include all five subregions described above (labeled "High" below). This market area would correspond to the highest potential demand for Montana coal if no changes are made in sulfur emissions regulations. With the proposed reduction in allowed emissions levels, the Illinois/Indiana region would face substantially higher costs in using Montana coal as compared to Illinois coal. The available coal contract information indicates that the two contracts for Montana coal deliveries to this region expire in 1978 and 1981; no information concerning their renewal has been identified. The second market area scenario (labeled "Mid" below) exlcudes the Illinois/Indiana region. This market area represents a moderate impact of new emissions standards, or the most likely long-term market area for Montana coal even without the new standards. Additionally, the maximum impact of lowered sulfur emission standards on the Montana coal market would appear to involve the loss of the Wisconsin/Michigan region, as well as most of the Midwest region. However, the Midwest

market appears to impact Wyoming almost exclusively rather than Montana coal production. The Midwest market, then, represents the third market area scenario (labeled "Low" below), consisting of Minnesota, portions of the Midwest, and the Pacific Northwest.

3. Coal Demand Projections

The three market area scenarios for Montana coal described above were applied to the utility power plant data base to derive projected coal demand levels for each of the five subregions for the years 1980, 1985, 1990, and 2000. The following assumptions were used in making these projections for all three market scenarios:

- The 1980 projected coal demand levels were developed from available coal contract information and actual shipments during 1976 and the first half of 1977, and include all new plants which have indicated use of Montana coal that are projected to be on-line prior to 1980.
- Growth rates in electric demand were taken at utility-projected levels through 1985 (about six to seven percent per year for peak capacity) and at a reduced level of about three percent per year following 1985, to reflect most economic projections of the impact of higher electric rates and to keep the number of scenarios small.
- All existing power plants for which long-term contracts for Montana coal were identified were included in each scenario. (Plants in Illinois/Indiana currently receiving Montana coal were excluded in the Mid and Low scenarios after 1980, reflecting the lack of information concerning renewal of these contracts.)
- All existing power plants in the market region currently using coal from non-Montana sources were assumed to continue their current coal supply, reflecting the large expense of converting boilers for different coals and the lack of present emphasis on extending more stringent sulfur emissions standards to existing plants.
- All proposed power plants for which information indicated existing contracts for Montana coal were included in each scenario.

- All proposed power plants in Minnesota were assumed to be supplied by Montana coal.
- In addition to existing contracts, approximately 1000 MW of unspecified plants in the Midwest region were assumed to be supplied by Montana coal in 1990 and 2000; approximately 300 MW in the Pacific Northwest region were assumed to be supplied by Montana coal in 1985 and 1990, and an additional 1400 MW by 2000. (These assumptions are highly judgemental, but represent relatively small amounts of coal.)

In addition, the following assumptions were made for the individual market scenarios:

- High Market Scenario--proposed plants beyond 1980 in Northern Wisconsin/Michigan were included in the projections, and Montana coal use in Illinois was assumed to maintain its 1980 projected share of total utility coal use in that state of roughly 15 percent;
- Mid Market Scenario--proposed plants beyond 1980 in Northern Wisconsin/Michigan were included in the projections; and no use of Montana coal in Illinois after 1980 was assumed, reflecting either the "natural" loss of this market to Midwestern coal or the impact of new sulfur emissions standards; and
- Low Market Scenario--only plants existing before 1982 (the assumed date of implementation of new emissions standards) were assumed to use Montana coal in Wisconsin/Michigan, reflecting a maximum impact of the new regulations; in the Mid scenario, it was assumed there would be no use of Montana coal in Illinois/Indiana after 1980.

Based on these assumptions, the projected levels of Montana coal demand by electric utilities are shown in Table IV-3. A regional summary of these projections is given in Table IV-4. Note that in all three scenarios coal-fired power plants in Minnesota represent the major market for Montana coal.

Figure IV-1 compares these three scenarios for future Montana coal demand to two scenarios taken from the Coal Demand Study ("All FGD" market area, constant growth in electric consumption, constant 1980 share of

TABLE IV-3

Projected Montana Coal Demand for Out-of-State Electric Utilities, 1980 to 2000

(Million Tons Per Year)

Market Scenario*	1980	1985	1990	2000
1. High	27.3	45.8	62.5	88.0
2. Mid	27.3	35.8	48.5	68.0
3. Low	27.3	28.3	40.0	55.0

---

* See text for scenario assumptions.

TABLE IV-4

Projected Montana Coal Demand for Out-of-State Electric Utilities by Region, 1980 to 2000

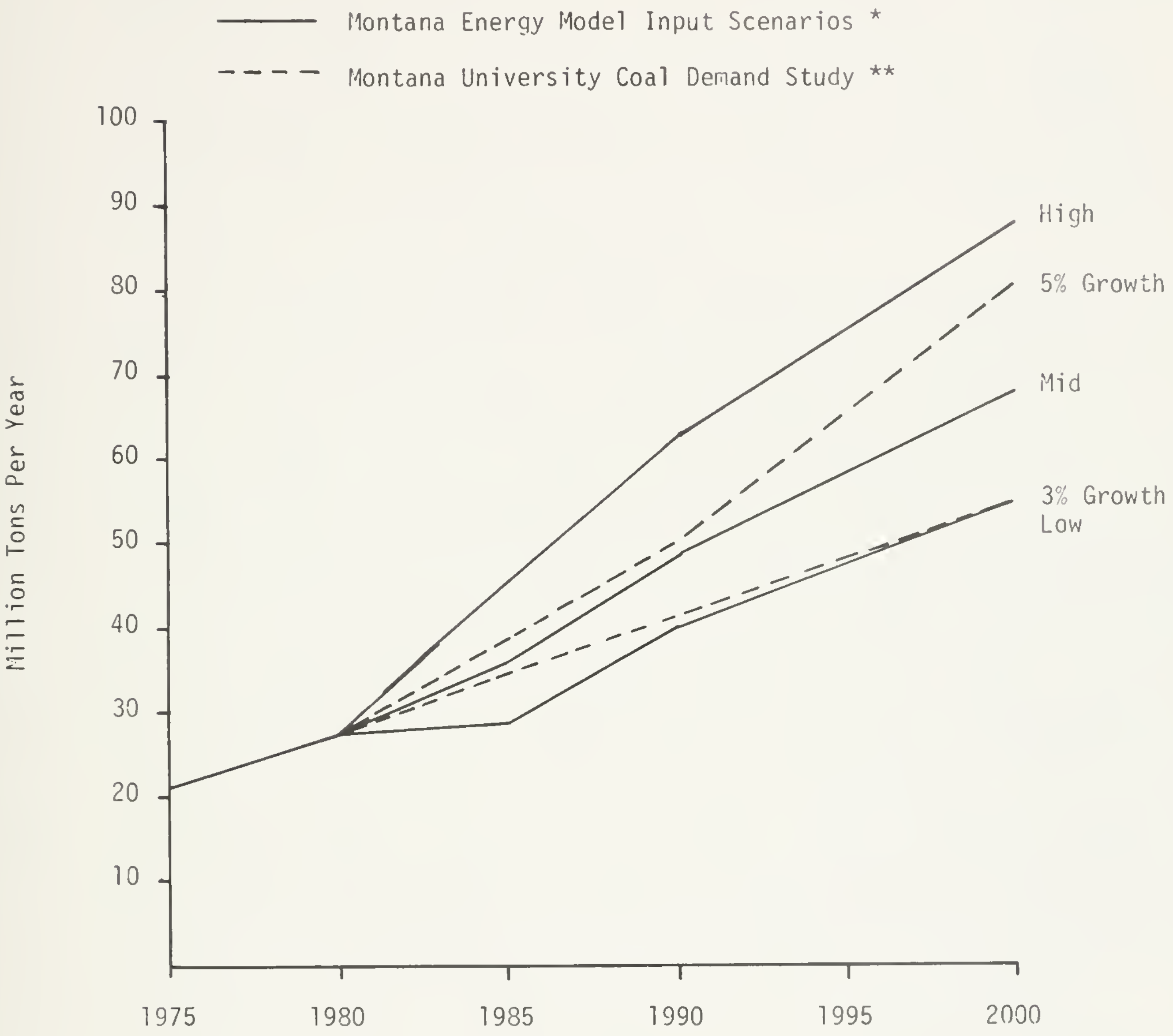
(Million Tons Per Year)

Market * Scenario	Region	1980	1985	1990	2000
1. High	Minnesota	10.5	20.5	29.5	40.0
	Wisconsin/Michigan	4.5	12.0	13.0	18.0
	Illinois/Indiana	10.0	10.0	14.0	20.0
	Midwest/Southwest	2.3	2.3	5.0	5.0
	Pacific Northwest	0.0	1.0	1.0	5.0
	Total	27.3	45.8	62.5	88.0
2. Mid	Minnesota	10.5	20.5	29.5	40.0
	Wisconsin/Michigan	4.5	12.0	13.0	18.0
	Illinois/Indiana	10.0	0.0	0.0	0.0
	Midwest/Southwest	2.3	2.3	5.0	5.0
	Pacific Northwest	0.0	1.0	1.0	5.0
	Total	27.3	35.8	48.5	68.0
3. Low	Minnesota	10.5	20.5	29.5	40.0
	Wisconsin/Michigan	4.5	4.5	4.5	5.0
	Illinois/Indiana	10.0	0.0	0.0	0.0
	Midwest/Southwest	2.3	2.3	5.0	5.0
	Pacific Northwest	0.0	1.0	1.0	5.0
	Total	27.3	28.3	40.0	55.0

* See text for scenario assumptions.

FIGURE IV-1

Projected Montana Coal Demand for Out-of-State Electric Utilitites, 1980-2000



* See text for market scenario assumptions.

** Coal Demand Study figures adjusted to remove Montana in-state use. Growth rates refer to alternate assumptions of annual growth in electric consumption within the coal market area.

Montana to total NGP coal demand, adjusted to approximately remove Montana in-state coal use). As can be seen, through 1990 the projections agree closely with the Mid and Low scenarios developed here. The flattening of coal demand in the Low Market scenario between 1980 and 1985 is due to the assumed loss of the Illinois/Indiana market which is matched almost exactly by increased Minnesota coal demand. In fact, considering the high degree of uncertainty in the year 2000 projections for both studies, the numbers presented in Figure IV-1 could be viewed as a regional disaggregation of the Coal Demand Study totals.

The projections presented indicate a relatively small impact on Montana coal demand because of the enactment of new sulfur emissions standards, representing about a 20 percent decrease in coal demand. Recent analysis using the Stanford Research Institute (SRI) Coal Depletion Model produced a similar result (at a somewhat lower total demand level), projecting Montana coal production at about 25 million tons per year (MT/Y) in 1985 under both the current standard (1.2 lbs. SO_2 per million Btu) and the range of new standards being considered. This is to be contrasted with the SRI analysis for Wyoming coal production, which projects a total demand of about 130 MT/Y in 1985 under the current emissions standard, but only 40 MT/Y in 1985 under the proposed new standards. This reduction by a factor of three would be caused primarily by the loss of the Midwest market region, which now is anticipating substantial use of Wyoming coal in new power plants. Note that an analysis similar to that of the Coal Demand Study might produce the same result for total NGP coal demand, but likely would underestimate Montana coal demand because of the assumption of a constant percentage of Montana to total NGP coal demand based on the 1980 coal contract precentage. The major impact of new sulfur emissions standards on western coal production appears to be concentrated in a market region currently not projected to receive substantial amounts of Montana coal, and hence, the standards have a much smaller impact on Montana coal production than on total NGP production.

4. Conclusions

The most probable level of future demand for Montana coal by out-of-state electric utilities appears to be about 30 to 35 MT/Y in 1985 and about

40 to 50 MT/Y in 1990. Substantial increases in industrial coal exports do not appear likely at this time; it seems certain that no major synthetic fuel plants using Montana coal would be on-line by 1985, and are unlikely even by 1990. Hence, total Montana coal production in 1985 would likely be 40 to 45 MT/Y (assuming seven MT/Y in-state use for electric generation and three MT/Y industrial use). The projections presented for the year 2000 are at best uncertain and are subject to several significant variables, including the development of synthetic fuels technology, the price and availability of natural gas and petroleum products within the coal market area, potential constraints on the development of midwestern coals (including concerns that a rapid near-term increase in midwestern coal use may result in another large increase in the demand for western coal in the mid to late 1990's since the midwestern reserves may be contractually committed by that time), and further revisions to pollution control standards.

Three major observations can be drawn from the projections of Montana coal demand presented above. First, this modeling study, based on a power plant-specific investigation, gives projected coal demand levels in substantial agreement with the projections developed by the more rigorous, but macroscopic, framework of the 1975 Coal Demand Study. Second, while Montana coal production is forecast to increase, it appears highly unlikely that it will reach the "boom" proportions that previously have been forecast and are implied by current mine production estimates of 90 to 100 MT/Y in 1985 and 100 to 120 MT/Y in 1990. Third, the potential impact on Montana coal production of new sulfur emissions regulations, which essentially would require flue-gas scrubbing of all coals, appears to be relatively small, at least in comparison with the impact forecast for Wyoming coal demand.

B. Oil

The oil supply submodel of the Montana Energy Model places emphasis on the production and distribution of crude oil rather than refined products for three primary reasons: Montana is historically a net exporter of refined petroleum products; any shortages of refined petroleum which occur will be national rather than regional or state-wide in scope; and the availability of crude oil,

specifically Canadian condensate, is currently one of the most pressing questions in Montana's economy.

The oil supply submodel examines five parameters:

- The production of crude oil in Montana;
- Reserves of crude oil, both proven and estimated undiscovered reserves;*
- Distribution systems for crude oil products and alternatives to the existing system;
- The existing refinery system, its demands and capabilities; and
- Canadian imports, their curtailment, and that curtailment's impacts.

1. Production of Crude Oil in Montana

The production of crude oil in Montana during the year of 1976 is listed on a field by field basis in Table IV-5. Figures IV-2 and IV-3 show the geographic location of these fields and show graphically the relative contributions of each section within the state. Montana's production of crude oil exceeded 32 million barrels in 1976 and 33 million barrels in 1977. Of this production, only approximately nine million barrels was available for in-state refining. The balance was contractually obligated elsewhere.

Estimates of proven reserves of crude oil are shown in Table IV-6. At the current rate of production (approximately 90 thousand barrels per calendar day), there are approximately seven years of proven reserves. Estimates of undiscovered recoverable reserves have been made by the U.S. Geological Survey for basins which lie in Montana. These estimates are shown in Table IV-7. The basins in Montana include the Folded Belt or Overthrust in southwestern Montana; the Sweetgrass Arch in the north; the Central Basin; the Williston Basin (which also underlies North Dakota); and the Powder River and Bighorn Basins (which partially underlie Wyoming).

Recent exploration in Wyoming and Idaho and trace discoveries in Montana suggest the estimates for the Folded Belt area are too low.

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* Those reserves which, although currently undiscovered, are estimated to exist in a favorable geologic setting.

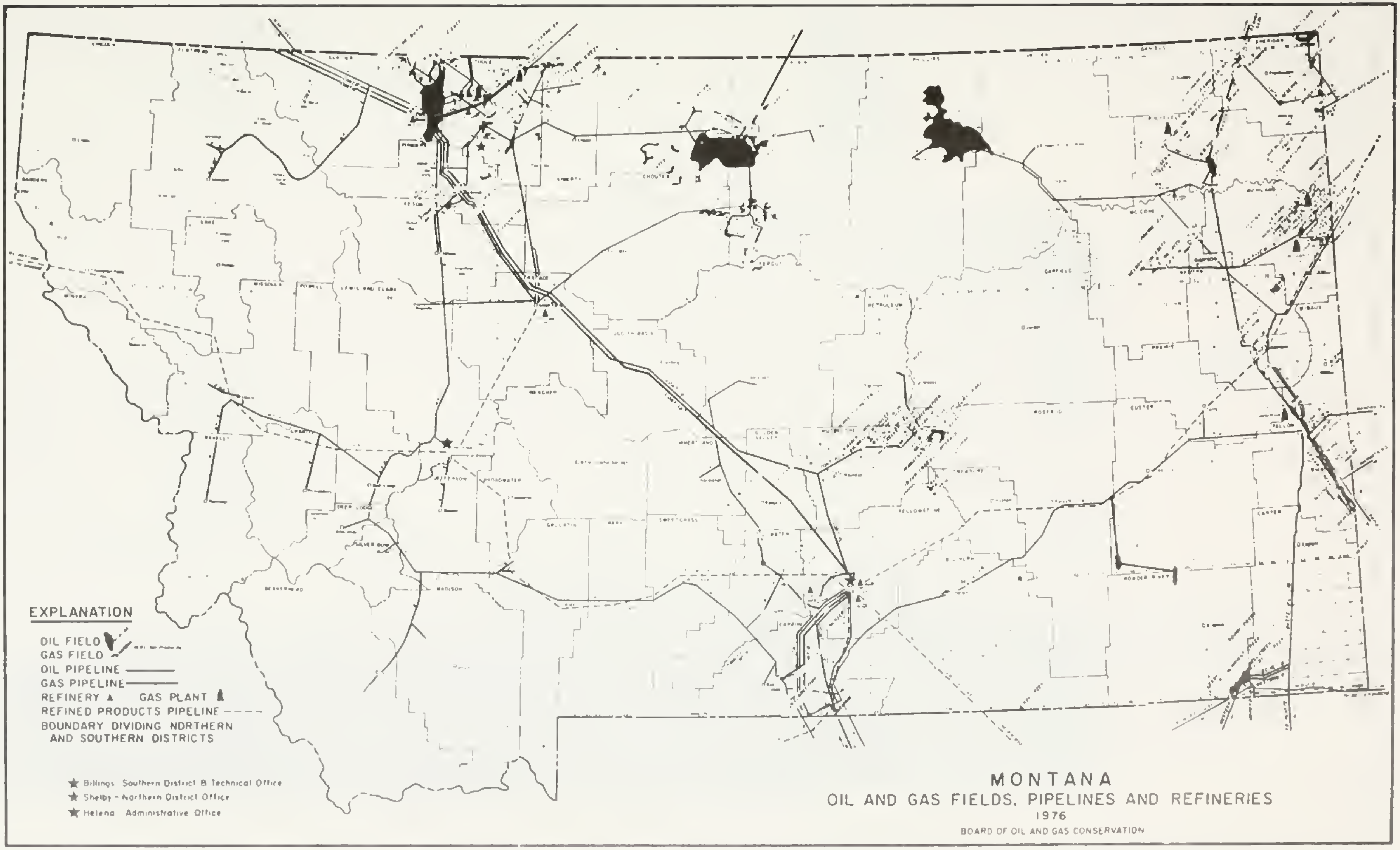
TABLE IV-5

State of Montana - Summary of Producing Oil Fields - 1976

Source: MONTANA BOARD OF OIL AND GAS CONSERVATION

FIGURE IV-2

Montana Oil and Gas Fields, Pipelines, and Refineries


EXPLANATION
OIL FIELD
GAS FIELD
OIL PIPELINE
GAS PIPELINE
REFINERY ▲ GAS PLANT
REFINED PRODUCTS PIPELINE
BOUNDARY DIVIDING NORTHERN AND SOUTHERN DISTRICTS
★ Billings Southern District & Technical Office
★ Shelby - Northern District Office
★ Helena Administrative Office
MONTANA
OIL AND GAS FIELDS, PIPELINES AND REFINERIES
1976
BOARD OF OIL AND GAS CONSERVATION

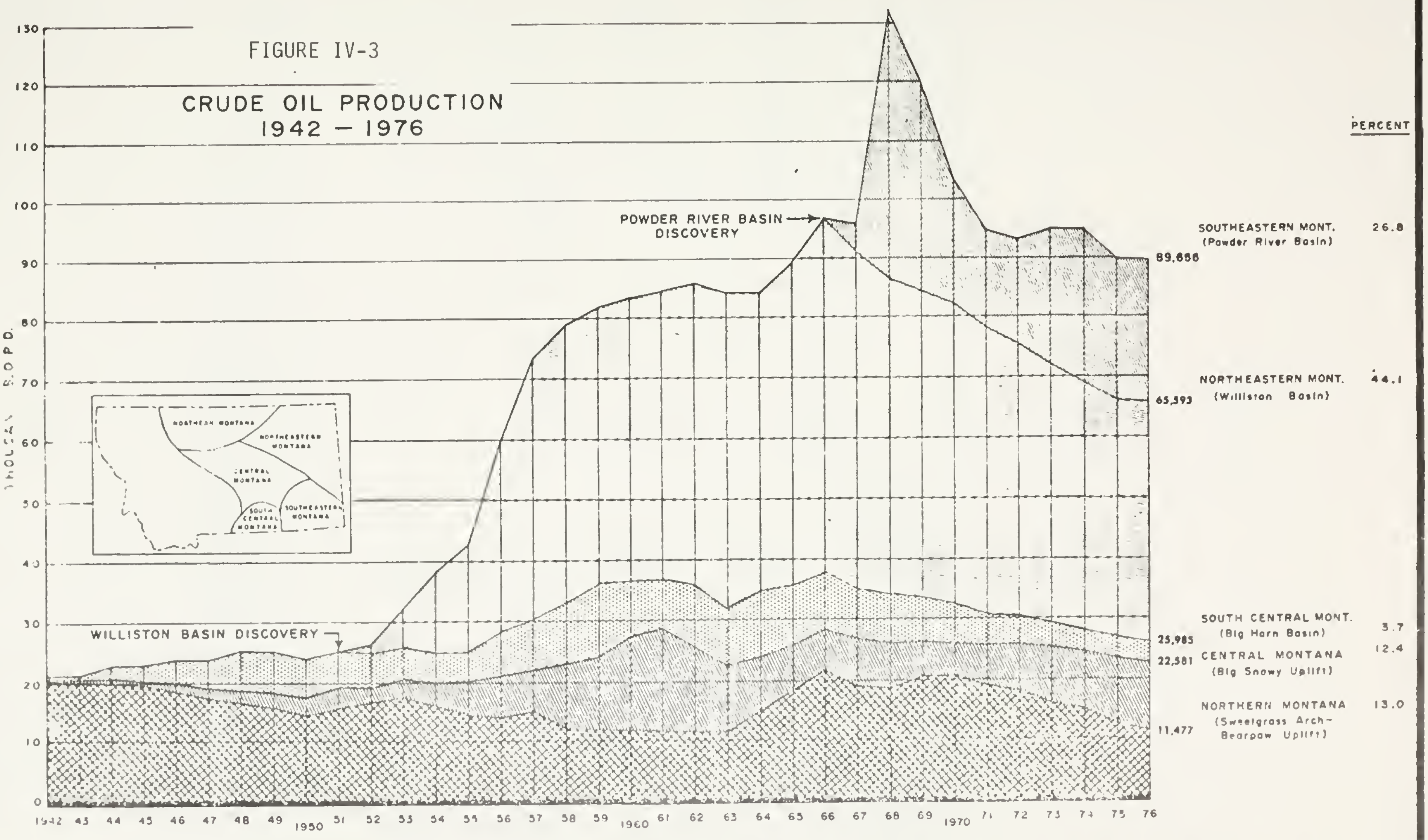


FIGURE IV-3

CRUDE OIL PRODUCTION
1942 – 1976

SOURCE: Department of Natural Resources

TABLE IV-6

Estimate of Montana Crude Oil
Proved Reserves, by Region, January 1, 1977

Region	Proved Reserves (million barrels)	Percent of Total
Northeastern Montana	40.8	18
Southeastern Montana	105.2	45
Central Montana	33.1	14
South Central Montana	9.8	4
Northern Montana	43.6	19
State Total	232.5	100

Source: Montana Department of Natural Resources and Conservation, Oil and Gas Conservation Division, Annual Review for 1976, Volume 20.

TABLE IV-7

Undiscovered Recoverable Reserves in Montana (1975)[1]
(In Billions of Barrels)

Basin (Locale)	Low Estimate P = 95%	High Estimate P = 5%	Mean
Folded Belt (SW Montana)[2]	Negligible	Negligible	Negligible
Sweetgrass Arch (N. Montana)	0.1	0.4	0.2
Central (Central Montana)	0.06	0.2	0.1
Williston (NE Montana - NW North Dakota)	0.4	2.5	1.2
Bighorn (Southcentral Montana - N. Wyoming)	0.5	1.5	0.9
Powder River (SE Montana - NE Wyoming)	1.0	2.5	1.7

Source: Gordon L. Dolton, U.S. Geological Survey, Resource Appraisal Group, Denver, Colorado, personal communication to Elliot Rockler, Missoula, Montana, March 3, 1978.

[1] Update in process.

[2] May be too low in light of recent activity in Wyoming and Idaho. (See The Oil and Gas Journal, August 7, 1977.)

Other recent increases in the price of oil which exceed inflation levels have prompted oil industry officials to state that economic reserves of crude oil may be underestimated by as much as 15 percent.

2. Transportation of Crude Oil

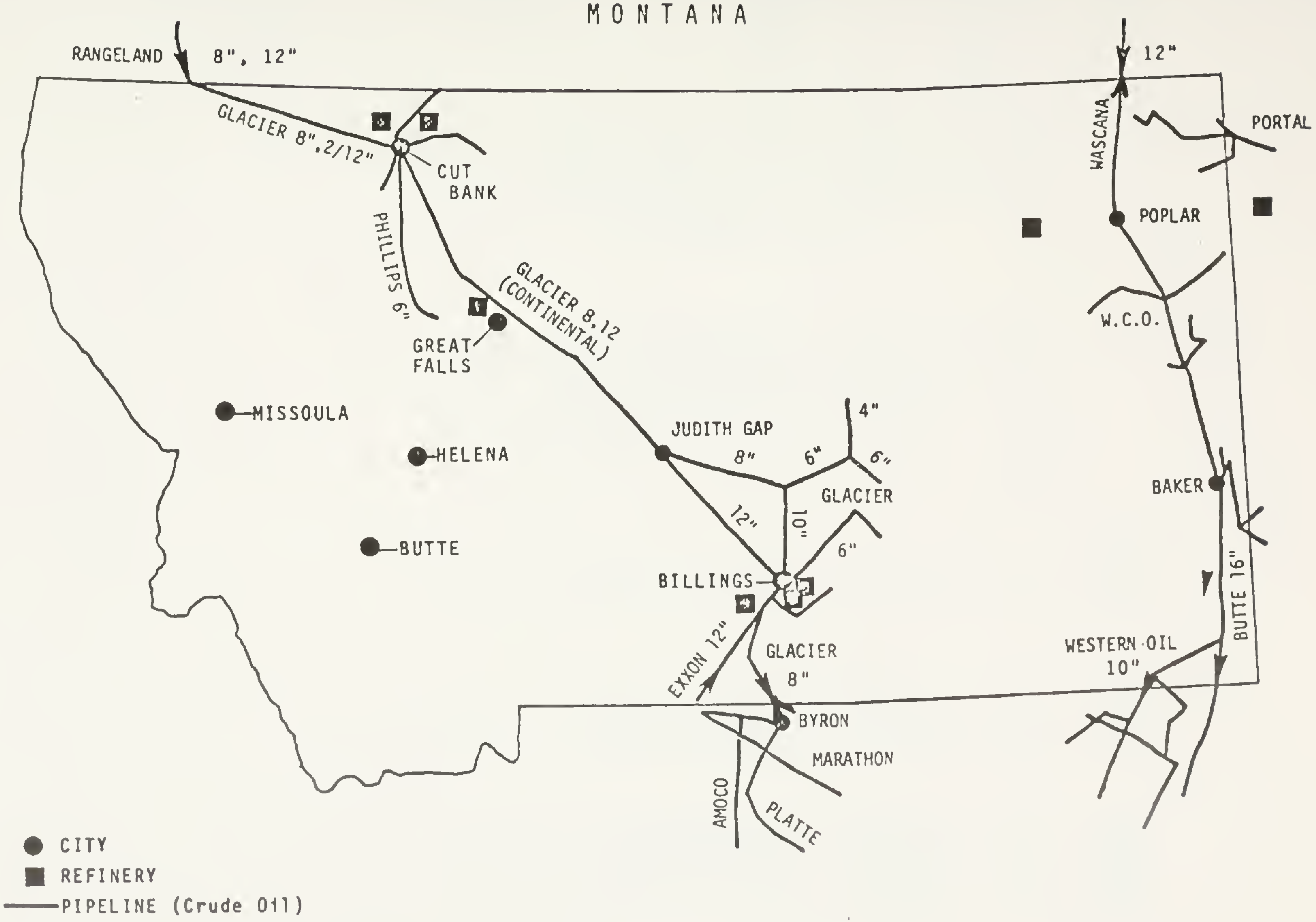
Montana currently has two major crude oil distribution systems. One is the Glacier System, owned by Phillips, Exxon, and Continental oil companies. The Glacier System carries Canadian, northern and central Montana crudes, and northern Wyoming crude oils to refineries in the Billings, Montana, area for refining. Crude not refined in Billings is transferred into the Platte Pipeline for delivery to midwestern refineries. The other major distribution system in the Butte System, composed of the Butte, Wascana, and Western Crude pipelines. The Butte System carries eastern Montana crude from the Williston and Northern Powder River Basins into the Platte Pipeline and, subsequently, midwestern refineries. Figure IV-4 shows the geographic locations of the crude oil distribution system in Montana. Throughput, capacity, and points of origin and destination for the system's components are given in Table IV-8.

The pipeline system map (Figure IV-4) illustrates why only nine million of nearly thirty-three million barrels of Montana crude oil were refined in Montana. The transportation system from the major producing fields in Montana is designed to export the crude oil into the Midwest. Estimates of proven and undiscovered recoverable reserves in Montana (Tables IV-6 and IV-7) indicate that these fields probably will remain major producers, and thus, the trend for crude oil exports will continue. Table IV-9 gives the destinations of Montana crude oil exports by state of destination and quantity received.

With the impending reduction of Canadian crude oil and condensate available for import, the crude oil distribution system will not be able to provide an adequate supply of crude oil to Montana refineries. Among the suggested alternative is "yo-yoing" sections of pipeline in order that flows can be reversed. This has been accomplished on two sections to date, and other sections are being considered. Those sections which have been reversed are the Glacier pipeline link from Frannie, Wyoming, to Billings, Montana, and the Wascana pipeline from Richey, Montana, to Regina,

FIGURE IV-4

Crude Oil Pipelines in Montana



Crude Oil Pipelines - Montana

TABLE IV-8

Montana Crude Oil Pipeline Data, Thousand Barrels Per Calendar Day (MBCD), 1977

Pipeline	From	To	Diameter (Inches)	Capacity (MBCD)	Throughput* (MBCD)	Source
Wascana	Poplar	Regina, Sask.	12	24.0	2.0-3.0	1,2
Western Crude	Poplar	Baker	10	NA	NA	1,6
Butte	Baker	Alzada	16	70.0	(NA)***	1,7
	Alzada	Osage, WY	16	90.0	(NA)***	1,7
	Osage, WY	Guernsey, WY	16	128.0	(NA)***	1,7
Portal	Culbertson	Grenora, ND	6	27.9	NA	
Continental	Alberta	Cut Bank	2-12	88.0	42.0	1,3
	Alberta	Cut Bank	8	30.0	17.0	1,3
	Cut Bank	Billings	12	62.0	42.0	1,3
	Cut Bank	Roundup	8	33.4	17.0	1,3
	Roundup	Billings	10	44.0	27.0	1,3
	(Billings	Laurel)**	4,8	48.3	14.5	1,3
	(Laurel	Billings)**	8	13.0	2.5	1,3
	(Frannie	Laurel)**	8	13.0	11.8	1,3
	(Byron	Frannie)**	8			
Phillips	Cut Bank	Great Falls	5	6.5	~6.0	1,4
Exxon	Wyoming	Billings	12	64.0	NA	1,5

*1977 Daily Average

**Reversible

***Available upon written request.

Sources are listed on the following page.

Sources:

1. Paul E. Polzin, Montana's Major Energy Transportation Systems, prepared for Montana Energy Advisory Office, Helena, Montana, 1976.
2. Ray Lock, Murphy Oil Company, Calgary, personal communication to Elliot Rockler, Missoula, Montana, March 1978.
3. Bob Miller, Continental Oil Co., Billings, personal communication to E. Rockler, Missoula, Montana, March 1978.
4. Phillips Petroleum Company, Great Falls, personal communication to E. Rockler, Missoula, Montana, March 1978.
5. Brad Fuller, Exxon, Billings, personal communication to E. Rockler, Missoula, Montana, March 1978.
6. Erroll Boyle, Western Crude Oil, Denver, personal communication to E. Rockler, Missoula, Montana, March 1978.
7. Richard Watson, Butte Pipeline Company, Houston, personal communication to E. Rockler, Missoula, Montana, March 1978.

TABLE IV-9

Distribution of Montana Crude Oil Exports by State of Destination

(Thousand Barrels)

Destination	1973	1974	1975	1976
Pennsylvania	346	360	769	368
Illinois	3,096	2,608	2,236	7,713
Indiana	13,720	14,435	10,907	7,422
Kansas	1,638	1,065	1,020	935
Minnesota, Wisconsin	1,199	1,617	2,026	2,029
Missouri, Nebraska	0	80	654	1,268
North Dakota	1,065	1,374	1,304	1,285
Ohio	80	115	59	225
Oklahoma	0	50	0	0
Colorado	793	573	256	83
Wyoming	654	361	498	26
Utah	0	0	784	0
Other States	0	0	0	1
TOTAL	22,591	22,638	20,513	21,355

Source: Itami, Montana Historical Energy Statistics, Montana Energy Advisory Council, February 1978, United States Department of Energy, Energy Information Administration.

U.S. Department of Energy, Crude Petroleum, Petroleum Products and Natural Gas Liquids, Fiscal Summary, Energy Information Administration.

Saskatchewan. There also has been consideration of switching the crude oil and refined products in a single pipeline. Although technically feasible, this suggestion is basically unworkable because of the location of product pipelines. Product pipelines generally run to markets which do not coincide with oil producing fields. Another transportation scheme which has been suggested is the Northern Tier Pipeline Company's proposal to construct a crude oil pipeline from Port Angeles, Washington, to Clearbrook, Minnesota. Unit train transport of Alaskan crude from Port Westward, Washington, to Cut Bank, Montana, and thence into the Glacier pipeline system also has been proposed. The Northern Tier Pipeline project currently is writing an environmental impact statement in anticipation of receiving the necessary permits. There appears to be strong environmental opposition to this project, especially in the state of Washington.

3. Petroleum Refineries in Montana

There currently are six operating refineries in Montana. These are Conoco, Exxon, and Cenex in the Billing area; Phillips in Great Falls; Westco in Cut Bank; and Kenco in Wolf Point. Until 1977, the Big West Refinery was operated at Kevin, Montana, but this facility has since been dismantled. The Big West operation was the most dependent upon Canadian crude oil.

With the exception of Kenco, all of the refineries are dependent upon supplies of Canadian crude. The extent of this dependence can be seen in Tables IV-10 and IV-11 and Figure IV-5. Kenco relies entirely on Montana-Williston Basin crude oil, which is trucked in, and exports all products by truck and rail. The National Energy Board of Canada has set a schedule for the reduction of Canadian exports of petroleum products to the United States. This schedule is in Table IV-12. Crude oil import allocations are expected to be zero by 1982; condensate import allocations are expected to fall to zero in 1985.

With the impending curtailment of Canadian crude and condensate, the question of refinery flexibility arises; that is, to what extent is it possible to replace "sweet", low-sulfur Canadian crude with crude oil from other sources? Each refinery has some flexibility to change the relative volumes produced of motor gasoline, heating oil, and residual fuel oil. These are basic constituents of any crude. Multiple variations

TABLE IV-10

BARRELS OF CRUDE OIL REFINED IN MONTANA — 1976

Fields	BIG WEST OIL CO.	CONTINENTAL OIL CO.	EXXON COMPANY	FARMERS UNION	PHILLIPS PETR. CO.	TESORO PETR. CO. (now Kenco)	WESTCO REF. CO.	TOTAL
Big Wall		65,089						65,089
Cat Creek		27,049		82,759	1,022,602			1,132,410
Cut Bank	57,285						1,255,077	1,312,362
Devil's Basin				316,599				316,599
Elk Basin		440,511	340,214					780,725
Flat Coulee							120,539	120,539
Fed & George Creek	202,345				106,765			309,110
Ivanhoe		30,079						30,079
Jim Coulee				188,125				188,125
Keg Coulee		126,244	15,344	25,055				166,643
Kelley			34,355					34,355
Kevin-Sunburst	305,829							305,829
Lodge Grass		7,286						7,286
Mason Lake		4,328						4,328
Melstone				14,709				14,709
Pondera					165,331			165,331
Ragged Point		122,379						122,379
Rosebud		69,422						69,422
Richey, Southwest						24,980		24,980
Snyder		5,502						5,502
Sumatra & Stensvad		947,795	601,534	532,412				2,081,741
Tule Creek & Others						718,036		718,036
Vaux				7,431				7,431
Volt						215,590		215,590
Whitlash					241,955		30,563	272,518
Winnett Junction				33,128				33,128
Wolf Springs			13,262					13,262
Total Montana Oil	565,459	1,845,684	1,004,709	1,200,218	1,536,653	958,606	1,406,179	8,517,508
Canadian Oil Imported	657,534	11,125,216	5,818,126	5,353,950	539,447			23,494,273
Wyoming Oil Imported		4,494,776	7,719,234	6,096,642				18,310,652
TOTAL Montana, Canadian & Wyoming Oil	1,222,993	17,465,676	14,542,069	12,650,810	2,076,100	958,606	1,406,179	50,322,433

PERCENTAGE OF CRUDE OIL REFINED

	Montana	Canada	Wyoming
Year: 1974	19.40%	35.79%	46.81%
Year: 1975	18.56%	40.28%	41.16%
Year: 1976	16.93%	46.69%	36.38%

AVERAGE BARRELS PER DAY

Montana	Canada	Wyoming	Total
25,537	44,487	61,627	131,651
24,463	53,077	54,237	131,777
23,272	64,192	50,029	137,493

REFINING FIVE YEAR COMPARISON

1972	1973	1974	1975	1976
48,464,721	50,967,206	48,052,776	48,098,535	50,322,433

Source: Montana Department of Natural Resources

TABLE IV-11

Crude Oil Refined in Montana Refineries
By Source of Crude (1000 barrels)

	Continental Oil (Billings)				Exxon (Billings)1/				Farmers Union (Laurel)			
Year	Montana	Wyoming	Canada	Total	Montana	Wyoming	Canada	Total	Montana	Wyoming	Canada	Total
1953	337	2753		3089	1067	6277		7344	949	3083		4032
1954	623	2277		2909*/	1641	5355		6995	1618	3234		4853
1955	1268	2077		3358*/	1778	5225		7004	1446	3908		5354
1956	560	2671		3231	1352	7095		8447	1916	3936		5852
1957	681	2795		3475	1777	6602		8378	1830	4249		6078
1958	807	2313		3120	2316	4445		6792	1395	3113		4509
1959	971	2793		3765	4414	6760		11173	1215	5589		6804
1960	728	3422		4151	3634	6175		9808	2008	4786		6794
1961	729	3955		4685	3583	5991		9574	1859	4092		5951
1962	1954	3434	185	5573	2519	9496	12	12028	2754	3740		6495
1963	2418	2241	1046	5705	2200	8739	495	11435	2974	3425		6699
1964	3732	1548	3692	8973	2275	9530	288	12093	2723	4603		7326
1965	2697	3068	4593	10359	2293	9659	37	11989	2635	3665		6300
1966	1773	4148	4674	10595	2318	9557	0	11875	2079	4415		6494
1967	1813	3936	5052	10802	2073	11851	0	13924	1833	5606		7439
1968	1714	1995r	10125r	13834	1451	12387	222	14060	1264	6533		7797
1969	1637	3443r	8482r	13562	1240	11964	360	13564	1539	6723		8261
1970	1351	3345r	9123r	13820	1090	11062	2381	14532	1355	4935	2404	8695
1971	1170	3592r	10070r	14833	1046	10997	2564	14607	1526	5143	3369	10038
1972	1119	3796r	12240r	17154	849	10821	3706	15376	1703	4625	4229	10556
1973	1046	3272r	12170r	16488	1089	10011	5568	16668	1672	4952	5299	11922
1974	1340	4299r	11113r	16752	744	8753	4870	14367	1599	3897	5697	11192
1975	1703	5478r	9291r	16472	879	8615	5606	15100	1466	5373	4339	11178
1976	1846	4495	11125	17466	1005	7719	5818	14542	1200	6097	5354	12651

1/ Formerly Humble Oil (1960-1972) and Carter Oil (1953-1959).
*/ Includes 9,000 barrels from South Dakota in 1954 and 13,000 barrels from South Dakota in 1955.
r Revised by the Montana Energy Advisory Council

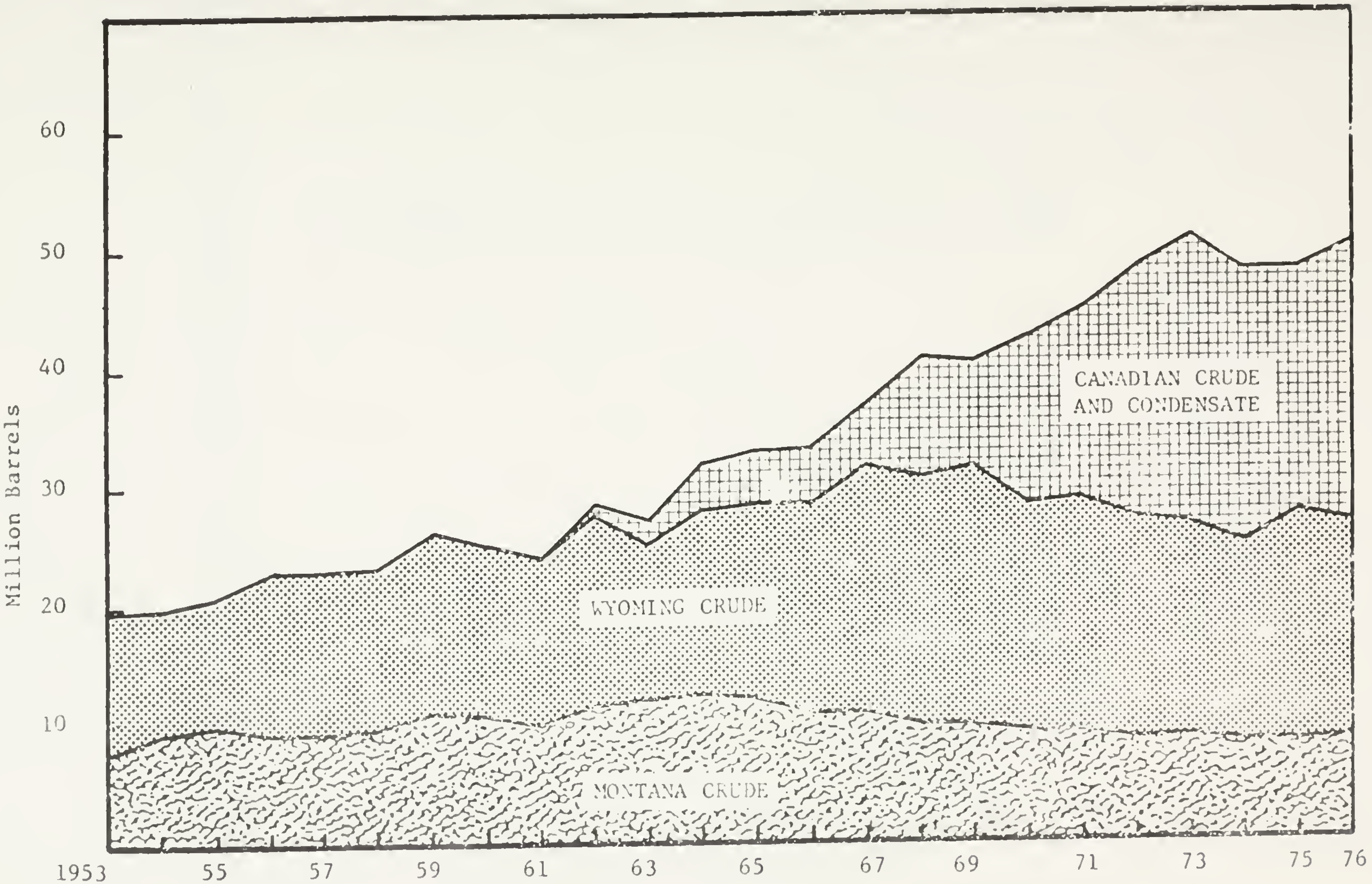
TABLE IV-11 (Continued)

	Big West Oil (Kevin)			Phillips (Great Falls)			Tesoro (Wolf Point)2/			Westco (Cut Bank)3/		
Year	Montana	Canada	Total	Montana	Canada	Total	Montana	Canada	Total	Montana	Canada	Total
1953	686		686	857		857				1305		1305
1954	652		652	839		839				1252		1252
1955	705		705	874		874				1279		1279
1956	729		729	997	7	1004	86		86	1257	47	1304
1957	742		742	831	16	847	98		98	1258	54	1312
1958	751		751	995		995	45		45	1203	12	1215
1959	805		805	1226		1226	55		55	1175	4	1180
1960	775		775	1298		1298	17		17	1142	21	1162
1961	831		831	1318		1318	0		0	1099	14	1114
1962	852	3	855	1436		1436	0		0	1050	41	1091
1963	916		916	1616		1616	0		0	1130	11	1141
1964	920		920	1491		1491	78		78	880	21	901
1965	1034		1034	1500		1500	508		508	1134	24	1158
1966	765		765	1619		1619	681		681	1159	9	1169
1967	967		967	1770		1770	747		747	1191		1191
1968	1290		1290	1690		1690	820		820	1258		1258
1969	1101		1101	1609		1609	861		861	1274		1274
1970	1207		1207	1691		1691	806		806	1338		1388
1971	1136		1136	1955		1955	843		843	1371		1371
1972	523r	705r	1228r	2120		2120	765		765	954r	276r	1230r
1973	675r	784r	1469	2220		2220	668		668	1057r	464r	1513r
1974	519r	940r	1459	2056	81	2136	590	23	613	1142r	392r	1534r
1975	398r	820r	1218r	1724	433	2158	687	4	690	1145r	166r	1311r
1976	565	658	1223	1557	539	2076	959		959	1406		1406

2/ Formerly Texstar Petroleum (1959-1964) and the Texas-Calgary Co. (1956-1958).
3/ Formerly Union Oil Company (1953-1970).
r Revised by the Montana Energy Office (formerly the Montana Energy Advisory Council)

FIGURE IV-5

Petroleum Refined in Montana, By Source of Crude Oil
(Million Barrels)



Petroleum Refined in Montana, By source of Crude
(In Million Barrels)

TABLE IV-12

Actual and Projected Canadian Crude Oil Exports to the U.S.

Year	Barrels (000)
1971	263,165
1972	312,440
1973	365,305
1974	288,715
1975	219,000
1976	169,725
1977	93,075
1978	60,590
1979	31,025
1980	20,075
1981	1,825
1982	0

Source: U.S. FEA, Office of Oil & Gas, Crude Oil Supply Alternatives for the Northern Tier States, 8/76.

are possible, including investment in the processes to convert residual oils into gasoline and heating oil and to upgrade the quality of that gasoline into premium gasoline. Second-guessing these possibilities and variables for each plant has not been possible.

For the northern Montana refineries, there is little question of flexibility. Westco depends entirely on Montana crude. Phillips supplements its Montana (Cut Bank) supply with approximately two thousand barrels of crude per day and has no alternative sources unless North Slope crude can be brought down from Alaska. (However, Phillips reports it has exchanges in place to keep up the Canadian in-flow.) The plant, as is, can handle the high sulfur Alaskan oil, but the proportion of high sulfur "bottoms" in the product mix--asphalt and residual oils (resids)--would increase. There is no local market for these substances, and marketability is critical to protect the area from overflowing asphalt. Southern Montana refineries at Billings depend heavily on Canadian crude. Their only immediate substitute is a heavy, "sour" mix Wyoming crude, and the "bottoms" problem exists for all three refineries. (All three have negotiated exchanges for immediate needs.)

Cenex (Farmer's Union) at Laurel estimates it could run 100 percent. Montana crude or 100 percent high sulfur, low asphalt Alaskan North Slope crude without modification and ship heavier products farther than it does at present. To process 60 percent Wyoming crude, however, currently would be uneconomic at the minimum throughput of 20,000 barrels per day. Cenex has considered adding a hydro-cracker or coker to enable it to process more heavy crude, but these are not feasible without expanding the refinery. Wyoming crude is not now available to Cenex in quantities which would exceed 60 percent of the minimum throughput. Cenex does receive Canadian crude on exchange (for Gulf Coast crude sent to eastern Canadian refineries) at an estimated rate of five thousand barrels per day.

The Conoco refinery operates a clean condensate unit, which brings its nominal capacity to 52.5 thousand barrels per calendar day (MBCD), to handle Canadian condensate. There is no substitute for this supply at present. When it runs out in 1985 (estimated), the refinery's nominal capacity will crop to 35.0 MBCD. Conoco has negotiated exchanges for

its Billings and Rangehall operations jointly; presently, these two are receiving 25.0 MBCD in exchanges and 21.5 MBCD in allocations. Condensate makes the refinery's operations flexible without modification. Crude and condensate can be mixed in varying proportions to produce to specification. However, the refinery may be uneconomic when condensate supply is gone.

The Exxon refinery recently expanded its coker capacity by 6,000 MBCD at a cost of $7,000,000 to increase its ability to recycle bottoms into distillates and thereby enhance its capacity to process Wyoming heavy crudes. Nevertheless, it still will have a surplus--asphalt and resids--position, like Cenex and Conoco, if it handles more heavy crudes. Currently, this refinery receives 2.0 MBCD on exchange and it anticipates substituting North Slope crude. It also may receive some Powder River sweet crude over a Marathon-Platte (reversal)-Glacier interconnection if this pipeline modification is undertaken. Minimum throughput to keep the Exxon refinery technically operational is about 30,000 barrels. To keep it economically operational, however, probably requires higher flow-throughs.

4. The Oil Supply Submodel

The oil supply submodel consists of two linked components: an oil discoveries submodel and an allocation submodel. The allocation submodel is included to compensate for the distribution systems' inability to deliver the bulk of Montana crude to Montana refineries. The allocation procedure utilized is simple: a five-year, moving average of the percentage of production available for Montana refineries is computed and applied to anticipated production.

The approach taken with the crude oil discovery submodel is predicated on three behavioral assumptions:

- Investment in exploratory drilling is a function of the anticipated return on that activity (e.g., higher oil prices stimulate exploration);
- The productivity of each successive dollar spent on drilling decreases as the finite amount of undiscovered oil reserves

decreases, (i.e., the probability of success decreases with respect to the amount of oil discovered); and

- Major discoveries of oil will encourage additional exploration because of the increased knowledge gained through that effort and also because of the increased psychological incentives which result from a major discovery.

Each of these behavioral characteristics is demonstrated to some degree in the historical data (e.g., the Bell Creek discovery of 1967). Recent increases in the world price of oil have encouraged additional drilling and drilling expenditures.

The three behavioral assumptions listed above have been defined as four mathematical functions dependent upon the previously defined five time periods. Initial data points are derived from historical data. The definitions for each of the four functions follow:

- F1 = Exploratory drilling $/Year vs. return ratio;
- F2 = Barrels (BBL) discovered/ $ spent vs. cumulative discovery;
- F3 = Drilling rate adjustment vs. discovery multiplier; and
- F4 = Size of a major discovery (BBL/Year).

Three variables describe historical averages for productivity, drilling rates, and a discovery multiplier. Two other variables describe resource availability and use in the state. These five variables together compose the stated variables in the submodel:

- S1 = Average productivity (BBL/$ spent);
- S2 = Average discovery multiplier;
- S3 = Normal drilling rate;
- S4 = Undiscovered oil (BBL); and
- S5 = Cumulative discovered oil (BBL).

The model has ten other variables, one exogenous, four derived, and five ancillary. The exogenous variable is

E1 = well head price of oil (1976 dollars).

The derivative variables are listed below:

- D1 = Smoothed productivity;

- D2 = Smoothed discovery multiplier;
- D3 = Normal drilling rate; and
- D4 = Discovery rate (BBL/year).

Ancillary variables for the submodel include the following:

- A1 = Return ratio ($/BBL)/(BBL/$ spent);
- A2 = Drilling rate ($/Year);
- A3 = Normal discovery (BBL/Year);
- A4 = Actual Productivity (BBL discovered/$); and
- A5 = Discovery ratio.

A flow chart of the oil supply submodel is shown in Figure IV-6. Variable names and numbers coincide with the numbers and definitions given. Output from the oil supply submodel includes all of the variables, with the exception of the derivative variables.

C. Gas

Montana has two major suppliers of natural gas: the Montana Power Company (MPC) and Montana Dakota Utilities (MDU). MPC supplies natural gas to the western two-thirds of the state and MDU supplies the eastern one-third. Nine other small utilities purchase gas from MPC and MDU for local distribution. Other gas producers in the state include Northern Natural Gas Company (NNG), which produces gas in northeastern Montana for export to Minnesota, and the Colorado Interstate Gas Company, which produces and purchases gas in the Elk Basin field in southeastern Montana for export south.

Each of the three largest producers (MPC, MDU, and NNG) serve distinct geographical areas and maintain separate distribution systems. MPC's and MDU's distribution systems have only one common point, and NNG has no common point with either of the other major producers. Competition in the state for gas is limited to four fields. The producing fields, first-year production, and purchasing utility for each field is shown in Table IV-13. Figure IV-2, in the previous section, shows the geographic location of each of these fields and the pipeline distribution systems. Pipeline size and ownership are noted on the map next to each of the pipeline segments.

The supplies of natural gas and reserves for each of the supplies will be discussed separately for each major distributor. Estimates of undiscovered

FIGURE IV-6--Flow Chart of Oil Supply Submodel of the Montana Energy Model

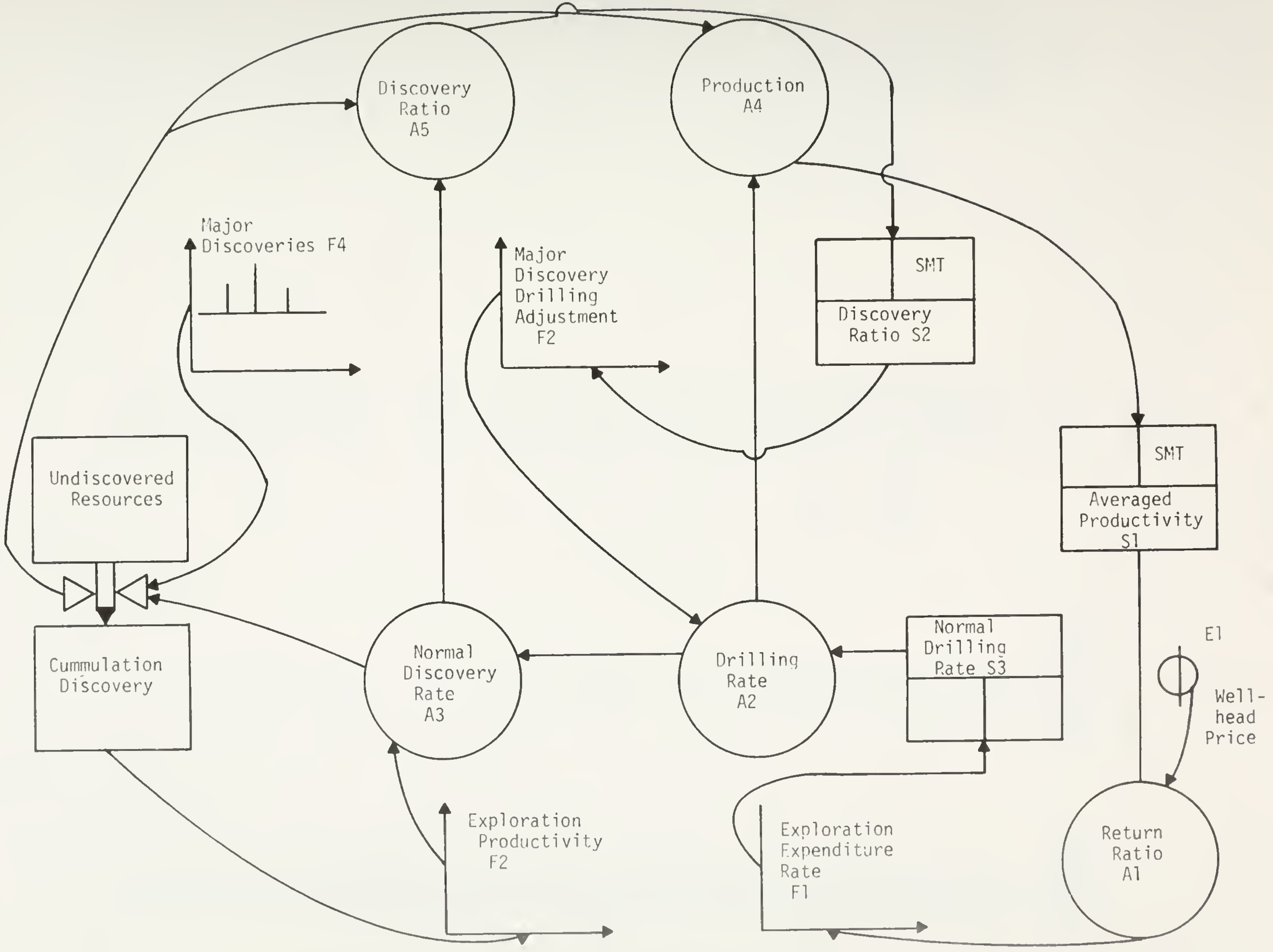


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TABLE IV-13

Montana Natural Gas Fields and Utility Purchase Patterns

FIELD	COUNTY	FIRST YEAR OF PRODUCTION *	UTILITY PURCHASER *
Alma	Liberty	1976	MPC
Bears Den	Liberty	1952	MPC
Black Jack	Liberty	1969	MPC
Bid Rock	Glacier	--	MPC
Bowes	Blaine	1926	MPC
Bullwalker & Area	Blaine, Choteau	1976	MPC
Canadian Coulee	Hill, Liberty	1974	MPC
Clark Fork North	Carbon	1975	MPC
Conrad Butte	Pondera, Toole	1976	MPC
Cutbank (reagan)	Glacier, Toole	1930	MPC **
Dry Creek	Carbon	1932	MPC
Dry Creek Middle	Carbon	1975	MPC
Dunkirk North	--	--	MPC
Flat Coulee	Liberty	1956	MPC
Fred & George	Toole	--	MPC
Gold Butte	Toole	1963	MPC
Grandview	Liberty	1959	MPC
-Gypsy Basin	--	--	MPC
Haystack Butte	Liberty	1941	MPC
Keith Block	Liberty	1952	MPC
Kevin Sunburst	Toole	1924	MPC ***
-Kevin Sunburst Nisku	Toole	--	MPC
Kicking Horse	Toole	1946	MPC
Kinyon Coulee Area	Toole	1976	MPC
Middle Butte	Toole	1963	MPC
-Miner's Coulee	--	--	MPC
Mount Lilly	Liberty	1964	MPC
-Prairie Dell	Toole	--	MPC
-Rocky Boy	--	--	MPC
-Sage Creek	--	--	MPC
Snoose Coulee	Liberty	1976	MPC
South Devon	Toole	1972	MPC
-South Shelby	Toole	--	MPC
Strawberry Creek	Toole	1975	MPC
Trail Creek	Liberty-Toole	1971	MPC
Utopia	Liberty	1949	MPC
West Butte	Toole	1972	MPC
Whitlash	Liberty	1930	MPC
-Willow Ridge	--	--	MPC
Ethridge	Toole	1973	MPC+
Rattlesnake Coulee (Associated Gas)	Toole	--	MPC

TABLE IV-13 (Cont.)

FIELD	COUNTY	FIRST YEAR OF PRODUCTION*	UTILITY PURCHASER*
Bowdoin	Phillips, Valley	1930	MDU+
Cedar Creek	Fallon	1921	MDU
Hardin	Bid Horn	1935	MDU
Liscom Creek	Custer	1972	MDU
Plevna	Fallon	1956	MDU
Pumpkin Creek	Custer	1957	MDU
Rapelje	Stillwater	1974	MDU
Swanson Creek	Phillips	1976	MDU
Associated Gas			
Bell Creek	Powder River		MDU
Cabin Creek	Fallon		MDU
Fairview	Richland		MDU
Four Mile Creek	Richland		MDU
Glendive	Dawson		MDU
Middle Sioux Pass	Richland		MDU
Otis Creek	Richland		MDU
Pine	Dawson, Prairie, Fallon, & Wibaux		MDU
Richland	Richland, Roosevelt		MDU
Sioux Pass	Richland		MDU
Sioux Pass, North	Richland		MDU
Sumatra	Rosebud		MDU
Tule Creek	Roosevelt		MDU
Black Coulee	Blaine	1973	Northern Natural
Brown's Coulee	Hill	1957	Northern Natural
-Chip Creek	--	--	Northern Natural (MPC, trace)
Coal Coulee	Hill	1975	Northern Natural
Fresno	Hill	1976	Northern Natural
Sherard	Blaine, Choteau	1974	Northern Natural

TABLE IV-13 (Cont.)

FIELD	COUNTY	FIRST YEAR OF PRODUCTION[1]	UTILITY PURCHASER *
COMPETITIVE FIELDS +++			
Big Coulee	Golden Valley, Stillwater	1956	MDU - 70% MPC - 30%
Lake Basin	Stillwater	1965	MDU ∼ 37.5% MPC ∼ 62.5%
Sawtooth Mountain and area	Blaine	1976	MPC ∼ 83% NN ∼ 17%
Tiger Ridge	Blaine, Hill	1969	MPC ∼ 18.0% NN ∼ 80%+
Elk Basin (Associated Gas)	Carbon	--	MPC ? MDU ?

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* Source: Montana Department of Natural Resources and Conservation, Oil and Gas Conservation Division, 1978.

** Cutbank Gas and Treasure State Power & Light produce a small amount of gas in this field for direct sale to consumers.

*** Treasure State Power & Light produces a small amount of gas in this field for direct sale.

+ Production from this field has supplied a refinery in the past, but probably goes to MPC at present.

++ Saco Municipal Gas produces a small amount of gas in this field for direct sale to consumers.

+++ Purchase percentages are calculaged according to January 1978 data.

reserves for state will be discussed as a single entity.*

1. Natural Gas Supply--Montana Power Company (MPC)

In contrast to the strong indications of future gas shortages prevalent over the past few years, the Montana Power Company (MPC) presently is in a supply surplus situation which is likely to continue for the foreseeable future. Although greater amounts of gas apparently will be available from MPC's supply sources, a primary reason for the improved supply situation is the substantial reduction in demand for MPC's gas. In response to the apparent supply crises and higher prices, MPC's industrial customers cut demand for natural gas by 3.441 billion cubic feet (bcf) between 1975 and 1976, and residential and commercial customers cut demand by 2.276 bcf for the same period. Natural gas sales reductions in all consumption sectors for the period totaled 5.841 bcf, or a little over 13 percent of MPC's total gas sales (i.e., 44.302 bcf in 1976).

MPC received the following amounts of gas annually from in-state production for the period 1973-1975:

MONTANA GAS TO MPC

1973	11.7 bcf
1974	10.3 bcf
1975	∿ 14.0 bcf
1976	∿ 15.0 bcf
1977	20.7 bcf

Source: MPC

The substantially increased use of Montana gas in 1977 reduced MPC's dependence on Canadian gas to 60 percent of its total supply as compared to 87 percent in 1973. MPC expects to continue using approximately 20 bcf of Montana gas annually in the future.

MPC drastically increased the budget for in-state gas exploration in 1971 through 1972 as shown in Figure IV-7 and has continued to allocate approximately the same level of funds shown for 1972 through 1975. However, higher gas prices since 1972 have had a positive effect on overall exploration activity in the state (see section 5, following) and MPC's reduced demand

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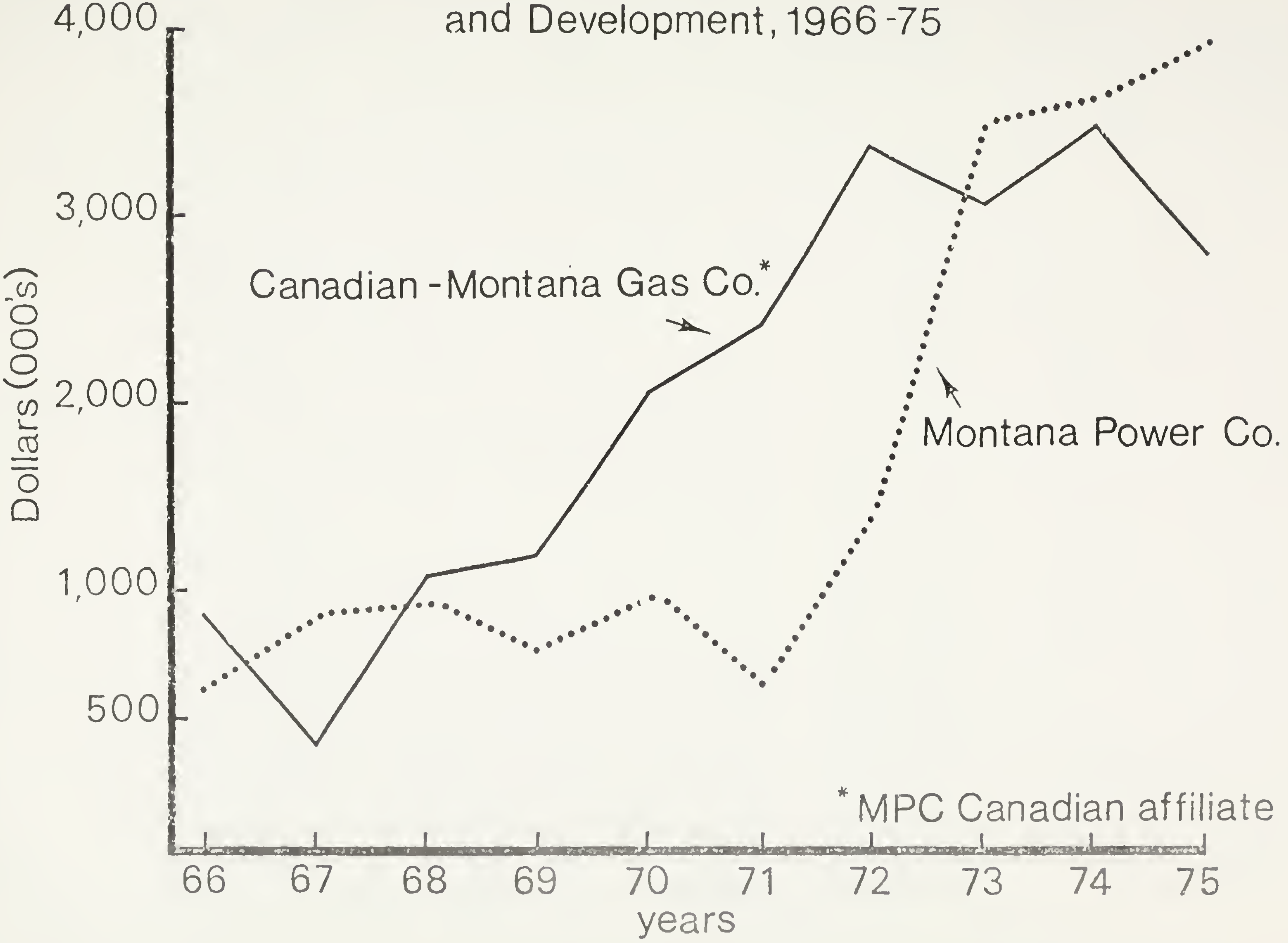
*Those reserves currently undiscovered which are estimated to exist in favorable geologic settings.

FIGURE IV-7

MPC Expenditures for Natural Gas Exploration and Development, 1966-75



*MPC Canadian affiliate

has caused the company to stop drilling many new wells or pursuing new development of reserves for the present. For example, the company acquired reserves in the South Bearpaw area of north central Montana in 1975 and drilled over 100 wells during 1975 through 1976, but while the present surplus situation prevails, development will not proceed further. MPC's supply has been augmented further by the purchase of about 19 bcf of additional reserves in the Leroy field of north central Montana from Fuel Company, a subsidiary of Colorado-Interstate Gas. At present, MPC does not want to inhibit exploration, but development of new reserves will be postponed in order to preserve the in-state supply as much as possible for the future.

The Canadian gas supply situation officially has remained unchanged since 1972 when Canada announced that export licenses would not be renewed. However, the availability of new reserves and continuing exploration seem to indicate that the future supply will be considerably greater than the National Energy Board anticipated in 1972 and that exports will be allowed to continue.

From a record total of 50 bcf of Canadian gas exported to Montana in 1973, the volume will be reduced according to the schedule shown in Figure IV-8 until the total amount authorized is exhausted in 1989. The exports are distributed between two licenses, one for Carway and one for Aden. The Aden license will expire in 1985 and the Carway license in 1993. However, because of accelerated rates of export in the past, MPC's total export volume limitation will be used up by approximately 1989.

One important change recently has been made in the license structure which allows MPC more flexibility than in the past. Although the allowable volume of annual exports remains unchanged, MPC has received permission from Canada and signed contracts commencing in November 1978 to shift up to 20 bcf per year from the Carway license to the Aden license. Gas from the Aden field historically has been approximately one-third purchased and two-thirds produced by MPC's subsidiary, Canadian-Montana Gas Limited. MPC will save by this new arrangement, because all Carway gas, by contrast, is purchased from Alberta and Southern Gas Company, Ltd. MPC's current surplus situation has made the expensive Canadian gas less attractive, but

Figure IV-8

Schedule of Reduction of Gas Imported from Canada

DATE	CARWAY	ADEN	ANNUAL TOTAL
July 1974	29.2	20	49.2
May 1975	29.2	10	39.2
May 1976	29.2	5	34.2
May 1977-1985			29.2
1985-1986			25.55
1986-1989			14.6
1990			0

SOURCE: Montana Power Company

the Alberta and Southern (Carway) gas is contracted on a "take or pay" basis. MPC recently has renegotiated this contract so that it will be possible to make up any prepayments of gas over the remaining life of the contract; however, if MPC delays in taking the gas, it is obligated to pay the price of the gas at the time of ultimate delivery. The present surplus situation has caused MPC to offer 2.5 bcf of Canadian gas per year to Montana Dakota Utilities (MDU) for a five-year period and an additional 250 million cubic feet (mcf) annually, if possible, which MDU would be obligated to use in Montana. This proposal has been approved by the state regulatory commissions in Montana and North Dakota but permission still is needed from South Dakota, Wyoming, and the Federal Energy Regulatory Commission (FERC); according to MDU, the proposal is likely to be approved.

MPC has indicated that more Alberta gas may be available in the future primarily because of increased reserves and a corresponding surplus situation in Canada. Development of the MacKenzie Delta gas field in the Canadian Arctic will make a major contribution to national supply, although this gas potentially will be as expensive as other Arctic gas. Due to reduced exports and increased reserves, Alberta also has a gas surplus which should continue for a minimum of five years. At present, the only pipeline leading out of the southeastern Alberta gas fields (i.e., Aden) extends into Montana. Alternative choices open to Canada would include shutting the gas in, constructing another pipeline into the Aden field, or allowing MPC to export the remaining reserves. MPC obviously hopes for the latter. MPC's subsidiary, Altana Exploration Company, presently is involved in gas explorations north of the Aden field which, if successful, would add to Canada's reserves and provide Canada with a further incentive to continue exporting gas in the future.

An estimated additional five bcf per year may be available to MPC by approximately 1983 depending on the construction and ownership arrangements associated with the Alaskan gas pipeline. MPC has a purchase agreement for 7.25 percent of Pacific Gas and Electric Company's (PG&E) share of Alaskan gas transported through the line. PG&E is part of the consortium called the Northwest Alaska Pipeline Company which will build the Alaskan portion of the line. The general route, which follows the Aleyeska

oil pipeline and the Alaskan Highway, received approval from the President and FERC late in 1977, but numerous permits and approvals still are needed from the Department of Interior and Transportation and from various Canadian agencies for specific segments of the route. In Canada the route follows the Alaskan Highway across the Yukon Territory to a point north of Whitehorse where the proposed Dempster Highway pipeline from the MacKenzie Delta area can be connected in the 1980's. Proceeding southeast across British Columbia and Alberta, the line will separate into east and west delivery systems at James River, Alberta.

It presently appears that these southern portions of the Alaskan line will be constructed first to carry Albertan surplus gas to the U.S. by 1980. The western leg of the pipeline would carry approximately 240 mcf per day of Alberta gas through Kingsgate, British Columbia and into the Pacific pipeline system by early 1980. The eastern line, which would cross the three northeastern-most counties of Montana, would carry 800 mcf per day to the midwestern U.S. The Province of Alberta must obtain export approval from the National Energy Board; it appears likely that permission will be granted on the condition that the gas be priced commensurately with the eventual purchase price of Alaskan gas and that an equivalent amount of Alaskan gas will be made available to Canada in the future. It is probable that the Alaskan gas could cost as much as five to six dollars per mcf. MPC supply projections indicate ten bcf from new Alberta sources in the 1990's; but MPC could be obligated to take this new gas when it becomes available in the early 1980's. If MPC's surplus supply situation continues, arrangements similar to the recent MDU contract may be necessary to dispose of the gas.

In the late 1980's to 1990's MPC is considering several other potential supply alternatives. The company owns natural gas acreage in the Green River Basin in Wyoming and in the Overthrust area in Utah. Also, MPC has had discussions with Champlin and Chevron Oil Companies concerning future supply from the Tickman Creek field in Wyoming, but no contracts have been signed.

MPC's current ten-year plan, filed in April 1978 in compliance with the Major Facility Siting Act, contains preliminary plans for a coal gasification facility of 35 mcf per year capacity which may be constructed in

partnership with MDU. Feasibility studies presently are underway to determine whether a unit of this size would be cost competitive; a larger consortium would be necessary to finance a larger facility, and state or federal assistance also may be needed.

In summary, Canadian, Wyoming, and Utah sources, coal gasification, development of Montana reserves, or some combination of these alternatives could provide from 20 to 50 bcf to the MPC system starting in the 1980's.

2. Natural Gas Supply--Montana-Dakota Utilities Company

Montana Dakota Utilities Company's (MDU) supply situation has improved considerably since April 1976 when it applied to the EPC for authorization to curtail gas deliveries to its industrial customers by 21.4 percent for the 1976-77 supply year. The curtailment plan ultimately would reduce the annual amount of gas sold to industrial customers by 40 percent, based on an average of the gas consumed from 1973 to 1975. Many of MDU's industrial customers either already have converted to other fuels or initiated conservation measures. In November 1976, Montana's Environmental Quality Council* reported that announced plans for conversion and conservation would reduce MDU's 1975 industrial demand for gas by 30 percent by 1980 and most of the remaining industrial demand would convert to other fuels (where possible) by 1985.

In filing its curtailment plan, MDU stated that the curtailments were necessary to maintain storage reservoirs at levels adequate to assure service to existing and future high priority customers. The Federal Power Commission initially refused to allow MDU to add new high priority customers (i.e., residential and small commercial customers) while in the process of curtailing its existing customers, especially since MDU anticipated a supply shortage by 1981 if the curtailments were not allowed and since the company would increase profits by redistributing its supply to new residential and commercial customers. An interim settlement authorized MDU to add 4000 new customers per year, system-wide, on the condition that the company add at least 30 bcf per year to its reserves. MDU met this requirement for 1976 and in 1977 added the new customers, 1220 of which are in Montana. In 1977 MDU added 35 bcf of new reserves to its holdings and in 1978 added 1186 new customers in Montana. In

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*Frizzel, Tom, Montana's Natural Gas Supply Crises, Environmental Quality Staff Report, Helena, Montana, November 1976.

1978 MDU expects to add considerably more than 35 bcf to its reserves. The FERC has not issued a final decision on MDU's curtailment plan and the associated addition of new customers, but the company anticipates eventual approval.

The reserves added in 1977 are located in Wyoming, North Dakota, and Montana, but a major source of future reserves apparently is located north of the Bowdoin field in Montana. The U.S. Geological Survey (USGS) has published information concerning this area as part of a program "designed to characterize natural gas resources in low permeability (tight) reservoirs in the Rocky Mountain Region."* The USGS Resource Appraisal Group is responsible for formulating estimates of the "gas-in-place" in areas included for study. The Northern Great Plains study area includes the Bowdoin area and the adjoining gas producing area of southeastern Alberta as a unified geologic province, shown in Figure IV-9. The lack of data on this territory has not been included in previous natural gas resource reports published by the USGS. In 1974 the Suffield Evaluation Committee, appointed by the Province of Alberta, evaluated a 1000 mile area with 76 gas wells and assigned an in-place gas reserve estimate of 3.7 trillion cubic feet. The same gas-bearing formation covers approximately 35,000 square miles in the U.S.; and based on the Suffield data, the formation should contain up to 130 trillion cubic feet (tcf) of gas in-place. Of this total, about 90 tcf is considered recoverable. A co-author of the USGS study reports that 100 tcf is located north of the Bowdoin field and that sand fracturing technology capable of recovering 5000 mcf per day is available, although this production rate would decline over time.

Approximately 40 percent of MDU's Montana demand comes from in-state production (about eight bcf) and the remainder is from Wyoming (about 12 bcf). MDU actually imports about twice that much gas from Wyoming, 23 to 30 bcf per year, and transports the remainder to North Dakota. MDU anticipates a gradual growth of imports from Wyoming in the future but declines to speculate on the amount.

The bulk of the company's exploration activities are conducted in Wyoming. MDU has been drilling only seven to ten wells per year in Montana and has no

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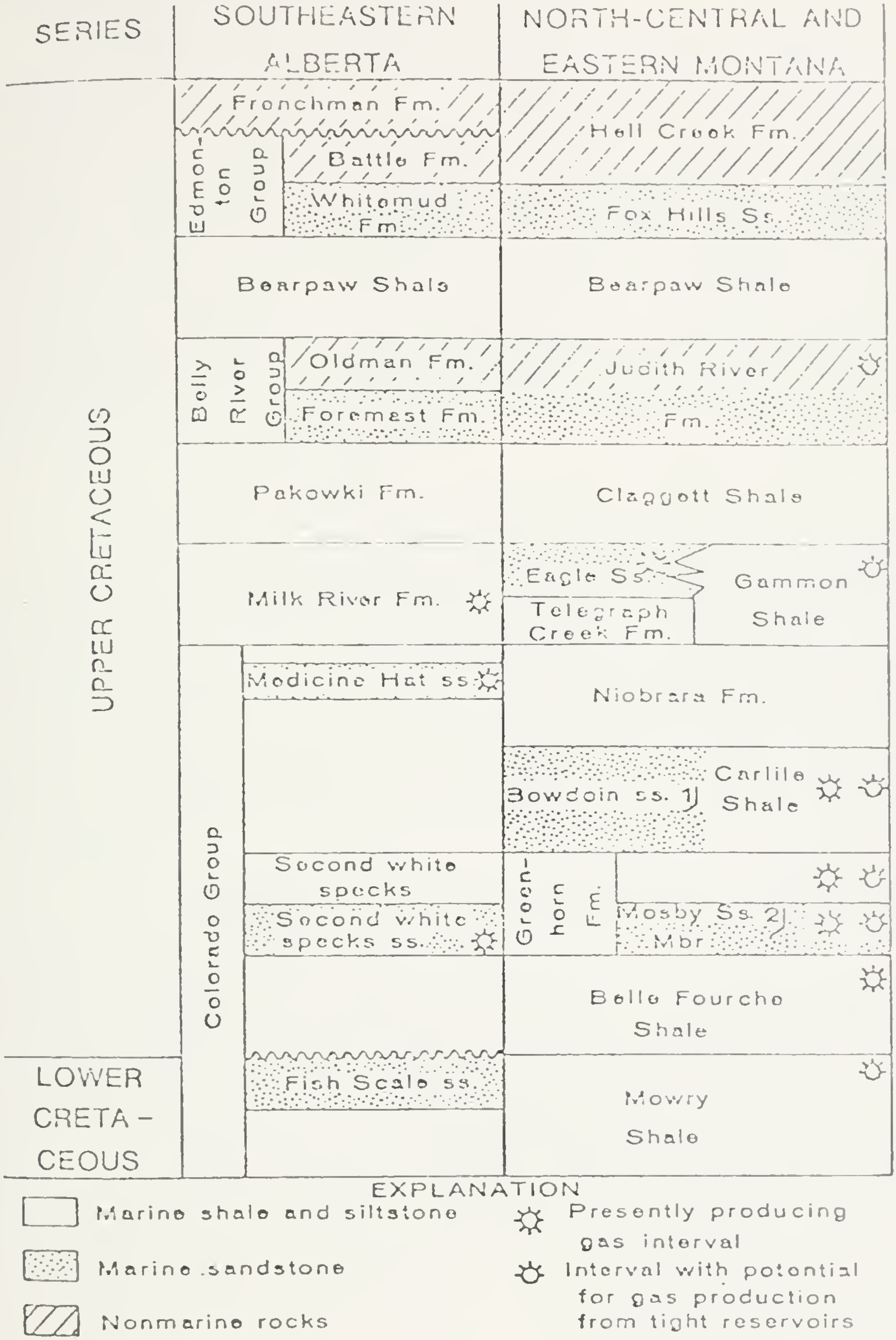
*U.S. Geological Survey, "Geological Program to Provide a Characterization of Tight, Gas-Bearing Reservoirs on the Rocky Mountain Region," Proceedings, Third Energy Research and Development Administration Symposium on Enhanced Oil and Gas Recovery and Improved Drilling Methods, Volume II, Tulsa, Oklahoma, 1977.

FIGURE IV-9

Stratigraphic Chart of Geologic Formations Producing Natural Gas and with Potential for Gas Production in the Northern Great Plains



Rice, USGS, 1977

1 Of subsurface usage

2 Correlates with Phillips sandstone of subsurface usage

plans to increase its explorations because it is presently operating at a deficit in Montana (-0.7 percent on earnings in 1977). Of the approximate 50 bcf that MDU distributed system-wide in 1976, 30 bcf came from Wyoming, 10 bcf from Montana, and 11 bcf from North Dakota.

As discussed in the previous section on MPC's gas supply, MDU will be receiving 2.5 bcf per year of MPC's Canadian gas and an optional 250 mcf per year specifically for distribution within Montana. This will be a five-year contract when approved by the federal and state regulatory agencies. This gas has not been included in MDU's reserve totals. MDU has been looking into the possibility of buying gas in Alaska and arranging to have it transported, but no commitments have been made and no estimates of the potential volume are available. Finally, MDU may obtain some gas from the joint coal gasification project with MPC (described in the previous section), but plans are still at the conceptual level.

3. Natural Gas Production

Natural gas production data by field are available from annual reports of the Oil and Gas Conservation Division of the Montana Department of Natural Resources and Conservation for the period from 1916 to 1976. This information is collected through the gas producer's license tax from each producer for each lease. Figure IV-2 shows the location of most of the fields in current production and Table IV-13 shows each field's first year of production; the annual data may be tabulated to show cumulative production for each field.

Since mid-1975 the Montana Department of Revenue, Miscellaneous Tax Division has collected annual natural gas production data by lease in association with the natural gas severance tax. Prior to 1975, this information was collected under the auspices of the gas distributor's tax. The total revenue derived from the annual production at each field is also available. The Department of Revenue and Department of Natural Resources have different reporting requirements, and as a result, there are discrepancies in the average range of one to five bcf between the total state annual production data available from each agency. Detailed analyses would be required to determine which source is more accurate.

4. Natural Gas Prices

Prices for natural gas consumed in Montana reflect a varied set of regulatory mechanisms and contract provisions. Detailed wellhead price information for gas produced in Montana is available from the natural gas severance tax files at the Miscellaneous Task Division of the Montana Department of Revenue. Figure IV-10 is an example of the information contained in these files. The severance tax files were begun when the tax became effective on July 1, 1975. Wellhead price information also has been available since July 1, 1977, in the oil and gas production tax files at the State Department of Natural Resources and Conservation. Gas producers file production and price information on a quarterly basis for each lease held. Each producer usually holds numerous leases, and each lease may reflect a different contract arrangement. Therefore, different prices are set for each of the leases.

Table IV-14 is a history of gas prices compiled by MPC. In 1970 MPC increased all gas prices to ten cents per mcf (for sweet gas) and from 1970 through July 1974 new gas prices increased from 16¢ to 55¢ per mcf. In July 1974 all contracts were increased to 40¢ per mcf. A portion of MPC's gas contracts are still at this price level. After May 1975 new gas prices increased sharply to a peak of $1.75 per mcf in July 1976. At that time Federal Power Commission (FPC) Opinion 770 set the price of new interstate gas at $1.42. Since MDU and Northern Natural Gas Company are both interstate companies, all gas purchased by these two companies is subject to the FPC order. Interstate companies also are obliged to reimburse producers for production taxes. In the Cut Bank and Shelby areas MPC has matched Northern Natural Gas Company (NNG) prices to deter competition. MPC also recently has paid the equivalent of the Canadian border price ($2.16 in the Gypsy Basin area south of Tiger Ridge in order to maintain a competitive edge. The interstate price for new gas escalates at the rate of 1¢ per quarter. MPC has been escalating at the same rate. Current prices for new gas are $1.47 and $1.80, respectively.

Figure IV-10

STATE OF MONTANA--DEPARTMENT OF REVENUE
NATURAL GAS TAX DATA PROCESSING SYSTEM

1977 Amoco Production Company (Field 099 Elk Basin)

Lease or Unit	No. of Wells	MCF of Gas Produced	Average Price per MCF	Punched Gross Value	Computed Gross Value
Madison 2	29	27,940.000	$0.155980	$4,358.03	$4,358.08
Embar Tensleep 2	32	181,823.000	$0.188773	$34,323.23	$34,323.27
Wy Madison 2		1,960.000-	$0.162745	$318.98-	$318.98-
Wy Embar Tensleep		13,555.000-	$0.270786	$3,670.51-	$3,670.50-
Subtotal	61	194,248.000		$34,691.77	$34,691.87
TOTALS		209,763.000		$38,681.26	$38,681.35
MCF Adjustments		15,515.000-			
Royalty Adjustments				$3,989.49-	$3,989.48-
Other Adjustments				$0.00	$0.01-
Values		194,248.000		$34,691.77	$34,691.86

Number 097801

Amount of Tax Punched - $921.01

Amount of Tax Computed - $919.33

Table IV-14

History of Gas Prices: Montana Production (¢/MCF)

1948-1954	5¢ for "sweet" gas 1.5 to 4¢ for "sour" gas
1954	MDU properties acquired at 3 to 5¢
1955	Cut Bank field increased to 6.5¢ for sweet gas
1956	MDU contracts in Shelby area increased to 6¢
1965	All old gas increased to 8.5¢ (sweet) New gas 9-3/4¢
July 1970	All old gas increased to 10¢ (sweet) and 8¢ (sour)
Aug. 1970	New gas increased to 16¢ (one contract signed)
Nov. 1972	New gas increased to 25¢ (no contracts signed)
July 1973	New gas increased to 40¢ (four contracts signed)
Feb. 1974	New gas increased to 45¢
May 1974	Two contracts signed at 55¢
July 1974	All old gas increased to 40¢
May 1975	New gas contracts range 45¢ to 85¢
July 1976	New gas $1.75

Other factors also affect price. Small gas producers receive 30 percent higher prices than large producers and high Btu gas commands a 1.1% higher rate. Also, pipeline quality gas delivered by the producers to the MPC pipeline system brings a considerably higher price, equaling present Canadian border price of $2.16.

MPC and MDU are gas producers as well as purchasers in some fields. In fact, utility-owned leases comprise the bulk of production at two of the largest fields, Cut Bank (MPC) and Bowdoin (MDU). In general, the utility-owned gas leases reflect the same rate paid for old gas, although the rate is used only for accounting purposes. MPC's royalty on gas leases is one-eighth of the wellhead value, or five cents for 40¢ gas. The royalty, a set rate of return, and a depreciation write-off are the amounts included in MPC's rate base.

Table IV-15 presents a pricing profile for six Montana fields representing a range of locations, number of years of production, and marketing situations and accounting for approximately 70 percent of total Montana production in 1976. Located in northeast Montana, the Bowdoin field is over 45 years old and is MDU's greatest single source of supply in Montana. Fidelity Gas Company, the largest producer in the field, is a subsidiary of MDU. The Cut Bank field, located approximately 80 miles east of Glacier National Park, is of similar age and is an important source of MPC's in-state gas supply. The Tiger Ridge field began production in 1969 and may be considered the major competitive field in Montana. NNG's pipeline system extends north to the Canadian border from this field and MPC's pipeline runs west. This field is located in north central Montana. Sherard is located directly south of Tiger Ridge and produces gas solely for NNG; it began production in 1974. Big Coulee and Lake Basin are located northwest of Billings and both are areas where MPC and MDU compete for supply. The data in Table IV-15 indicate that the greatest upward shift in new gas prices for all six fields occurred between the fall of 1976 and mid-1977, although the specific timing of the shift varies by field.

Table IV-15 (Cont'd)

Prices for quarters ending: (¢/MCF)

FIELD	PRODUCER	TOTAL PRODUCTION[1]	Dec '75	March '76	June '76	Sept '76	Dec '76	March '77	June '77	Sept '77
	MPC	17.4%	40¢	40¢	40¢	40¢	39¢	41¢	41¢	41¢
	Western Natural Gas	4.8%		48-72¢	46-69¢	46-69¢	46-69¢	44-69¢[8]	44-69¢	41-70¢
	Wainoco Inc.	trace		79¢	69¢	69¢	69¢	69¢	54¢-$2.03[9]	93¢-$1.49
Sherard	Wise Oil Co.[6]	100%	60¢	57¢	56¢	58¢	58¢	58-62¢	62-87¢	No data
	Northern Natural	trace		49¢	50¢	51¢	79¢	$1.18	90¢	90¢
Big Coulee	MPC	∼ 69%		42¢	41¢	47¢	42¢	40¢	40¢	40¢
	West Gas[11]	∼ 16%		63¢	62¢	62¢	$1.11	$1.13	$1.13	$1.13
Lake Basin	MPC	62.5%	40¢	40¢	40¢	40¢	40¢	40¢	40¢	No Production
	West Gas[11]	∼ 25%		66-72¢	66-71¢	64-69¢	$1.14-1.37	$1.15-1.30[12]		

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[1] Based on January 1978 Production Data

[2] Odessa Natural Corp. accounts for ∼ 7.6% of total production in January 1978, but this company apparently did not operate in the Bowdoin field in 1976 or 1977.

[3] Two leases, accounting for about 3 of the total production for this company received $1.36/MCF.

[4] These prices account for the bulk of production, but about 32% of the total received an average of $1.09 in June and $1.43 in September 1977.

[5] All other producers surveyed for this field report 40¢ prices.

[6] This company supplies Northern Natural Gas Company

[7] Percentages based on third quarter 1977 production.

[8] One lease received 85¢ beginning this quarter.

[9] Over half of the total production from this company received $2.03 this quarter.

[10] Percentages for this field are based on 1976 annual production.

[11] This company sells to Montana Dakota Utilities.

[12] Approximately half of the total production received at least $1.26 to $1.27.

Table IV-15

Price Profile for Six Montana Gas Fields*

FIELD	PRODUCER	TOTAL % PRODUCTION[1]	PRICES FOR QUARTERS ENDING: (¢/MCF) Dec '75	March '76	June '76	Sept '76	Dec '76	March '77	June '77	Sept '77
Bowdoin	Fidelity Gas (MDU)	56%	5¢*	5¢*	5¢*	8-13¢ (10¢*)	10-18¢ (13¢*)	21¢*	17-18¢[3]	17-18¢
	Midlands Gas	~ 32%	51¢	51¢	51¢	51¢	51¢	51¢	77-83¢[4]	92¢*[4]
	Miami Oil[2]	~ 2%					38¢	49¢	91-93¢	$1.20
Cut Bank	MPC	~ 96%	40¢ →							→ 46¢
	Cut Bank Gas (utility)	~ 2.6%	40¢ →							→
	Fulton	trace	40¢ →							→
	Energy Reserves	trace				86-90¢	86¢*	$1.79-1.93	$1.79-1.89	
	Texaco[5]	trace	51¢	51¢	51¢	51¢	51¢	51¢	51¢	
Tiger Ridge	Tricentral[6]	68.5%								
	LEASE:[7]									
	Bullhook	34%	49¢	48¢		54¢	54¢	53¢	$2.37	
	Sorenson	8%	No Data					66¢	$1.40	$1.42
	O'Neil	6.5%	No Data				58¢	56¢	$3.35	$1.42
	Davey (27-5-32)	6%	50¢	50¢		57¢	57¢	57¢	$3.28	$1.67
	Solomon	trace	46¢	46¢		49¢	47¢	47¢	74¢	$2.52

SOURCE: Montana Department of Revenue, Miscellaneous Tax Division

* Average

Wyoming gas imported by MDU for consumption in Montana is subject to interstate price regulation. Thus, all Wyoming gas from wells drilled since mid-1975 costs at least $1.42 plus production taxes and a $.01 per quarter escalation rate. However, 1976 Wyoming price information supplied in MDU's Form 2 report to the Federal Power Commission indicate that most of the supply is old gas purchased at under 40¢ per mcf, except for one rather large contract with Palmer Oil Company at the Pavillion field with a $1.21 per mcf price.

Canadian gas prices are set at the border and are based on million Btu's of energy rather than volume (i.e., mcf). MPC receives the gas at two delivery points, Carway and Aden. Table IV-16 includes a history of the border prices up to the present level of $2.16/mcf. It should be noted that the prices through January 1977 are in Canadian dollars. The Canadian dollar equivalent is actually $2.32.

Carway gas is purchased from Alberta and Southern Gas Company, Ltd., a Canadian subsidiary of Pacific Gas and Electric Company. An MPC subsidiary, Canadian-Montana Gas, Ltd., produces the Aden gas. Although subject to the same border price as Carway gas, this gas returns a royalty to MPC in somewhat the same manner as MPC's leases in Montana fields, although the situation is more complex. A portion of the border price, 86¢ at present, is redistributed back to the gas producers, but the rebate is offset by the producers' tax obligations to the provincial government. From 1952 to 1973 the royalty was 16-2/3 percent of the wellhead price. On January 1, 1974, the rate increased to a minimum of 22 percent with provision for escalating with price to a 50 percent maximum.

MPC has not made any formal study of future gas prices, but the company applies a six percent annual escalation rate to present prices. In a Montana Energy Advisory Council study published in early 1977, it is noted that Canada will most likely keep the border price of natural gas close to the price of the Organization of Petroleum Exporting Countries (OPEC) oil delivered at Chicago. It appears that new in-state gas production will be influenced by the interstate gas price either as a direct result of competition in the field or as part of an effort to keep competition out of certain fields. Nevertheless, a substantial portion of Montana's producing fields are served only by MPC's intrastate pipeline system.

Table IV-16
History of Canadian Gas Prices (¢/MCF)

ADEN

Year	Wellhead	Royalty
1952	5¢	0.8¢
1958	8¢	1.3¢
1959-1971	8 1/4 - 11 1/2¢ (1/4¢ escalation/year)	1.4 - 1.9¢
1972	15 1/2¢	2.6¢
Jul. 1973	23 1/2¢	3.9¢
May 1974	51¢	17¢
Jan. 1975	86¢	33¢
Aug. 1975	$1.26	40¢
Nov. 1976	$1.45	83¢
Jan. 1977	$1.50	90¢

CARWAY - BORDER PRICE (Canadian $/mcf at 14.73 psia)

1961	17.4¢
1962-1972	22.4 - 24.8¢
1973	23 - 46¢
Jan. 1974	35 - 46¢
Jul. 1974	62 - 67¢
Jan. 1975	$1.00
Aug. 1975	$1.40
Nov. 1975	$1.60
Sept. 1976	$1.80
Jan. 1977	$1.94
Sept. 23, 1977	$2.28 ($2.16 - U.S. dollars)

5. Recoverable Reserves

Recoverable reserve estimates are quantitative measures of the total gas resources existing in known reservoirs. The amount that ultimately will be recovered is difficult, if not impossible, to determine because it is dependent upon an interrelated set of economic considerations which change over time; e.g., price and the supply of gas available from a range of sources. Only a portion of the reserves may be recovered, depending on location, geologic characteristics, and the associated expense of extracting the gas. For example, current analyses show that present reserve estimates should be increased by 15 percent nationwide to account for the positive influence of higher prices.

The procedures used to formulate reserve estimates can affect accuracy, especially for new reservoirs which do not have historic rates of production to complement measurements of pressure and geologic data. Further, the source of any given set of reserve estimates can reflect special interest group influences--resulting in somewhat higher or lower figures, depending on the circumstances.

Aside from questions of accuracy and the amount of estimated reserves which may actually be recovered, the most significant problem with obtaining reliable estimates is the proprietary nature of field-specific information. The economic status of individual producers may be revealed through field-level reserve estimates. Therefore, most published estimates are expressed in terms of state totals, and in most cases, the data base is not open to public inspection. The volume of data required to formulate reserve estimates at even a regional or state level is also prohibitively large and therefore expensive to accumulate and analyze. To date, all known reserve studies relating to Montana have been conducted at the national level. The following text will discuss estimates acquired for this report and future options for obtaining more reliable estimates.

The American Gas Association (AGA) is probably the most commonly quoted source of reserve estimates and, for the most part, is the only source of historical reserve statistics. The AGA data are expressed in terms of total ultimate recovery, or the sum of proven reserves (the gas

underlying existing wells) and cumulative production at the field level. Reserves are estimated by work committees composed of representatives from companies operating in a given area. U.S. Department of Energy (DOE) personnel report that the reserve estimating process (and therefore, the results) reflect special interest influences even though operators' monthly production reports provide the basis for the statewide reserve totals. The AGA's 1976 recoverable reserve estimate for Montana is 1,106,270 mcf; this figure reflects a 15 percent increase over the 1975 estimate. Historical estimates are published in Montana Historical Energy Statistics, published by the Montana Energy Office in Helena.

For over 30 years AGA kept the field specific data underlying its state estimates confidential, except for two occasions. In 1975 the U.S. Geological Survey gained access to the data base in order to formulate basin level estimates, which totaled 901,000 mcf for Montana using 1974 as the base year. The Federal Energy Administration (FEA) also once obtained reserve estimates from AGA for the 50 largest producing fields in the nation. AGA is negotiating reluctantly with the DOE at the present time for complete release of the field-level data. This information is likely to be made available over the next few months.

In response to a Congressional request, the FEA conducted and published a survey study of recoverable reserves in 1975 entitled Oil and Gas Resources, Reserves and Productive Capability--Final Report (FEA, 1975). Approximately 95 to 96 percent of U.S. gas producers provided well-specific reserve estimates using five years of production through 1974 as a base. The administration declared this data base confidential, but published the state totals. FEA (now DOE) personnel report that even if the data base were accessible, the wells are not identified by county in the computerized file. For this reason, it is not possible to disaggregate the state reserve totals. The total estimate for Montana is 733,146 mcf, scaled from an 87 percent survey response.

The Federal Energy Regulatory Commission (FERC) has field-specific reserve data supplied by interstate gas companies. This information, required by FERC Form 15, is expressed in terms of total remaining recoverable reserves in a field and the amount the company has under contract or the dedicated remaining reserves. In fields where there is no competition

for the supply, as is the case with most of MDU's operations in both Montana and Wyoming, these data are field totals. Tables IV-17, IV-18, and IV-19 contain information from FERC Form 15. The Big Coulee total has been adjusted to reflect a field estimate, even though MPC takes about half the production. The Lake Basin totals cover MDU's operations only, and MPC's portion of this field is not included. The totals in parentheses are taken from MDU's 1976 Form 2 report to the Federal Power Commission (now FERC). These totals include reserves located on acreage actually acquired by MDU and apparently do not include reserves under wells operated by independent producers, which may explain the greater totals reported in 1977 for all fields except Rapelje. Thus, the total reported reserves are not field totals.

As an intrastate company MPC does not report field-specific reserve data to any government agency, but MPC has agreed to supply MERDI with reserve data. Further data showing reserve estimates for associated gas fields in Montana have been requested from FERC. All but three fields are MDU, and of the remaining three, two will be included in MPC's data. Big Coulee in Musselshell County is not near either utility's pipelines and the purchaser of gas from this field is not known.

In 1976 the State Oil and Gas Conservation Division sent out a survey to all gas producers in Montana requesting well-specific pressure data which could be used to formulate reserve estimates. Some large producers responded (notably MPC) but others protested the inquiry on grounds of confidentiality, and some did not report. The response to the survey was so incomplete that no meaningful analyses were possible.

The most promising future source of recoverable reserve estimates is a current effort to update the FEA survey conducted in 1974-1975. The study is being managed by the Oil and Gas Reserves Program within DOE. A preliminary report of survey results containing data through 1977 was schedulred for release in November 1978.

6. Undiscovered Recoverable Reserves

No new estimates of undiscovered recoverable gas reserves in Montana are known to have been published since the report Undiscovered Natural Gas Resources of Montana, was released by the Montana Energy Advisory Council in July 1976. The study included three estimates, developed by the

TABLE IV-17

Recoverable Reserves in Montana Fields Serving Montana Dakota Utilities

(All Volumes in mcf, 14.73 psi, at 60^0 F)

FIELD	RESERVOIR	TOTAL REMAINING RECOVERABLE	1976 (FORM 2)	DEDICATED REMAINING RECOVERABLE
Cedar Creek (Baker)	Judith River Eagle	NL* NL		NL NL
	TOTALS	48,064	(36,075)	48,064
Cedar Creek	Judith River	105,417		105,417
Liscom Creek	Shannon	9,758	(7,244)	9,758
Bowdon Creek	Bowdon Phillips	NL NL		NL NL
	TOTALS	106,721	(94,775)	106,721
Lake Basin	Eagle Telegraph Creek			
	TOTALS	4,222		4,222
Lake Basin N.	Eagle	113		113
Rapelje	Judith River Claggett Eagle	NL NL NL		NL NL NL
	TOTALS	912	(1,328)	912
Big Coulee	Lakota	1,656		1,656
Hardin	Frontier	474	(338)	474

Source: FERC Form 15, 1977

*Not Listed

TABLE IV-18

Recoverable Reserves in Wyoming Fields Serving Montana-Dakota Utilities

(All Volumes in mcf, $10^3 ft.^3$, at 60°F and 14.73 psi)

FIELD	RESERVOIR	TOTAL REMAINING RECOVERABLE		DEDICATED REMAINING RECOVERABLE	(COMMENTS)
		1977	1975		
Elk Basin South	Torchlight	NL*		NL	
	Middle Frontier	NL		NL	Producer is Continental Oil
	Peay	NL		NL	
	Dakota	NL		NL	
	Morrison	NL		NL	
	TOTALS	1,103	NA	1,103	
	Peay	1,139	(1,058)	1,139	Producer is EXXON
Riverton East	Frontier	NL		NL	
	Muddy	NL		NL	
	Lakota	NL		NL	
	Nugget	NL		NL	
	Phosphoria	NL		NL	
	TOTALS	48,151	(52,989)	48,151	
Muddy Ridge	Wind River	NL		NL	
	Fort Union	NL		NL	
	Lance	NL		NL	
	TOTALS	2,360	(1,975)	2,360	
Pavilion	Wind River	NL		NL	
	Fort Union	NL		NL	
	TOTALS	62,373	(68,295)	62,373	
Alkali Butte	Dakota	0	(1,831)	0	
Manderson	Muddy	4,277	(3,823)	4,277	Mobil
	First Frontier	459	(713)	459	Boydston & Franson
	Muddy	1,204	(1,635)	1,204	Newman Bros.
Big Polecat & S.E. Big Polecat	Frontier	NL		NL	
	Peay	NL		NL	
	TOTALS	894	(6,152)**	894	
Elk Basin	Embar Tensleep	2,171	(255)	2,171	
Riverton Dome	First Cody	NL		NL	
	Frontier	NL		NL	
	Dakota	NL		NL	
	Lakota	NL		NL	
	Phosphoria	NL		NL	

TABLE IV-18 (cont.)

FIELD	RESERVOIR	TOTAL REMAINING RECOVERABLE		DEDICATED REMAINING RECOVERABLE	(COMMENTS)
		1977	1975		
Byron South	Torchlight	133	(132)	133	
Poison Creek	Fort Union	207	(245)	207	
Silvertip South	Frontier	NL*		NL	
	Dakota	NL		NL	
	Phosphoria	NL		NL	
	TOTALS	2,933	(1,074)	2,933	
Joe Creek	Muddy	218	(519)	218	
Recluse	Muddy	NL	(2,169)**	NL	
Carter Draw	Morrison	17	(731)	17	
Worland Dome	Second Frontier	NL		NL	
	Third Frontier				
	Fourth Frontier				
	TOTALS	34,803	(47,737)	34,803	
Howard Ranch	Lance	786	(625)		
Madden Deep	Fort Union		(65,688)		
	Fort Union		(20,832)		
	Lance		(14,164)		
	Cody		(13,128)		
		13,508 1)			1) Not a field total; includes only MDU's 12½% interest.
Spear	Federal	853	NA		
Whistle Creek	Frontier	169	(370)		

Source: FERC, Form 15, 1977 and WY Oil & Gas Cons. Div.

*Not Listed
**1974 Data

TABLE IV-19

Recoverable Reserves in Montana Fields Serving: Northern Natural Gas Company

(All Volumes in mcf, 10^6 ft. at 60°F and 14.73 psi)

FIELD	RESERVOIR	TOTAL REM.REC. DRY	DEDICATED REM.REC. DRY	OTHER JURIS P/L PURCHASER
Sherard	Eagle Sands	697,700	682,280	
	Judith River	7,110	7,110	
	TOTALS	704,810	689,390	
Tiger Ridge	Eagle Sand	1,863,250	1,862,660	Montana Power Co.
	Eagle Sand	1,212,730	1,208,340	
	Judith River	310	310	Montana Power Co.
	Judith River	5,350	5,320	

Colorado Interstate Gas

Elk Basin	Tensleep	24,729	24,729	AMOCO Production Co.

Source: FERC Form 15, 1977

U. S. Geological Survey's (U.S.G.S.) Resource Appraisal Group, the Potential Gas Committee, a gas industry sponsored group which works through the Colorado School of Mines; and a special Steering Committee organized by the Montana Energy Advisory Council. This report contains explanations of the terminology and methodology employed by each group to formulate the estimates. The Potential Gas Committee's estimate is a statewide total, but the U. S. Geological Survey and Steering Committee estimates are broken down by the five geographic basins wholly or partially located in Montana. The aggregated statewide estimates from each source are as follows, in trillion cubic feet:

- U.S.G.S.--3.12 (plus or minus 0.61)
- Potential Gas Committee--5.60; and
- Steering Committee--7.06.

The main item accounting for the Steering Committee's higher total is a very high estimate assigned to Montana's Overthrust Belt area. This region may contain as much as five trillion cubic feet of recoverable reserves, but no major discoveries have been made to date, even though substantial expense and effort have been expended by many companies for many years. Drilling costs are very high in the mountainous, isolated terrain which commonly characterizes this region, and the bulk of the most promising sites are in Glacier National Park and other protected mountain areas; a recent test hole in Granite County cost about $1.25 million before completion.

In early 1978 at least three companies were drilling in the Overthrust areas of Granite, Beaverhead, and Glacier Counties, but by late April most of the activity ceased for various reasons. American Quasar plugged one hole at Peete Creek in Beaverhead County, but will continue to drill at one other hole called the Rebish Well. Damson Oil abandoned its wildcat in western Glacier County. Some minor oil and gas showings appeared but none had commercial potential. Trans-Texas Energy and Nyvatex Oil found some promising traces of oil in February on the north side of the Flint Creek valley in Granite County but recently abandoned the hole because the oil is migratory. Seismographic work will be undertaken next and more drilling at two new sites in the same area is planned for July of this year. May Petroleum Company has obtained drilling permits for a site in Beaverhead County, but has not yet begun work. All of this information was obtained through either the companies involved or the Oil and Gas Conservation Division.

7. The Natural Gas Model

Based on the information presented on natural gas, any mathematical modeling procedure which is to be effective must consider the following:

- Declining industrial demands caused by higher prices and uncertain supply;
- Institutional constraints placed on production in the form of production quotas and take-or-pay contracts;
- A large number of potential supply points, each subject to a different probability of success, and different prices per thousand Btu's of gas delivered;
- Physical resource limitations associated with given supply points;
- The potential for changes in end-use efficiencies; and
- Random peak loads, which never can be totally eliminated.

The Montana Energy Model uses a linear programming algorithm with explicit compensation for the probabilistic nature of gas production and supply. Linear programming techniques are used for optimizing an objective function, subject to mathematical side conditions or constraints. For the particular application at hand, the objective is to minimize the total cost (z) at price (c_i) of the resource (j_i) with probability (p_i), subject to constraint (a_i) of source (x_i) meeting requirement (r_i):

$$\text{Minimize } z = \Sigma\, c_i\, p_i\, x_i, \text{ where} \qquad \text{(Eq. IV-1)}$$

$i = 1...n$, and subject to

$\Sigma\, a_{ij}\, x_i \geq r_i$, where

$i = 1...n$;

$j = 1...m$; and

$x_i \geq 0$

The last constraint, $x_i \geq 0$, is a non-negativity constraint which precludes negative production from a given resource.

Four basic types of constraints can be identified in the linear program. These are supply, capacity, demand, and peaking (or balance) equations. Supply equations constrain the program to remain within the physical constraint of each resource. Capacity equations compensate for the institutional constraints associated with each field; these constraints may set

either upper or lower boundaries on the supply of gas from any give resource. Demand equations allow the model to compensate for changes in efficiency, industrial consumption, etc. Peaking and balance equations force the system to maintain an available reserve to compensate for the random nature of peak loads.

Because the objective function contains a probabilistic term, which implies that the goal is a minimization of expected costs, a methodology for computing the expected costs must be developed.

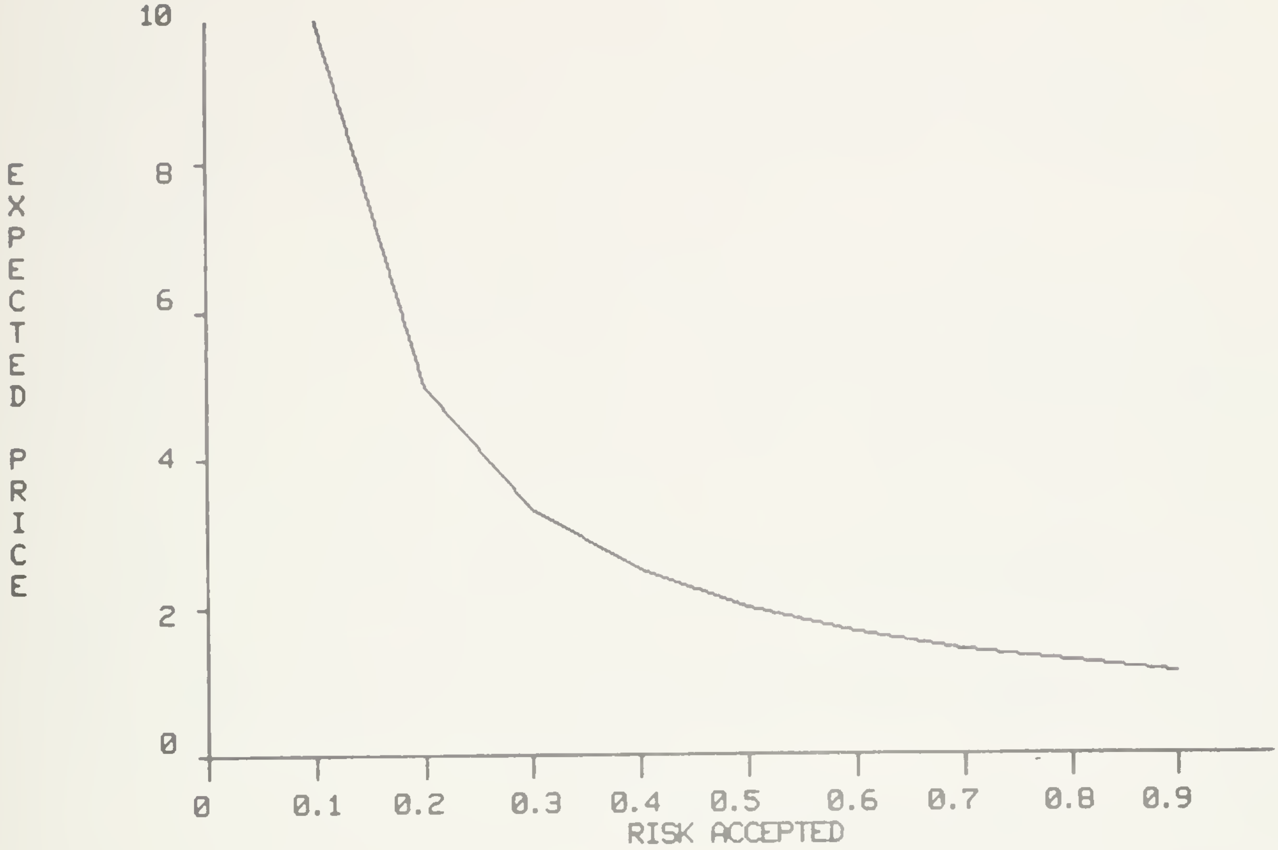
The necessity for computing an expected cost figure springs from the implicit optimization of two goals: the minimization of costs and the simultaneous attempt to minimize the risk associated with the supply process. This optimization of two goals necessitates a trade-off: does one wish to secure the supply for the future at very high cost or chance future supplies in order to minimize costs? Obviously, neither of these extremes are desirable and some trade-off criteria must be established--this criteria is the expected cost.

The expected value of an event is defined as the probability of that event's success multiplied by the return generated by the event. The rational entrepreneur or producer seeks to maximize the expected value of any investment decision, or conversely, minimize the expected cost of a decision. The expected cost can be mathematically defined as the reciprocal of the probability of success multiplied by the return (price) of that event. The behavior of the expected cost with respect to risk is shown in Figure IV-11.

There are five potential supply sources which appear to be viable alternatives over the modeled time period. These sources are Canada, Montana, Wyoming, the Arctic, and coal gasification. (Wyoming sources include some resources in Northern Utah which are owned by MPC.) Not all of these resources are available at any one point in time; coal gasification is not probable until 1990 and Canadian sources are expected to have diminished significantly by then.

Costs for the gas provided from each source are based on present costs or engineering estimates of costs at the point in time at which the alternative becomes viable. Gas costs from each of the alternative sources are assumed to increase at six percent annually. Probabilities are assigned subjectively on the basis of an examination of known reserves, estimated undiscovered reserves, and prior success ratios in the area.

Figure IV-11
Expected Costs of Gas



D. The Electrical Supply Submodel

The electrical utility industry is representative of a pure energy delivery system. Electricity is a major component of today's energy environment and a major component of any future scenario, offering the major alternative for the replacement of fossil fuels in the near and intermediate future. The abundance of coal for conversion to electricity in Montana and the West makes the electrical portion of the Montana Energy Model central to the model's efficiency as a planning device.

The supply submodel examines the present supply of electrical power from both hydro- and thermal-electric facilities and the distribution system which is utilized. The submodel also examines the current load structure and develops the rationale and logic for future supply and demand modeling.

1. Existing Hydroelectric Facilities

Hydroelectric power in Montana is presently generated from 22 facilities. Thirteen of these are owned and operated by the Montana Power Company (MPC), two are owned by out-of-state utilities, six are federally managed projects, and one small unit in northwest Montana is owned by Montana Light and Power Company.

The thirteen Montana Power Company facilities are listed in Tables IV-20 and IV-21. Table IV-20 presents nameplate capacity ratings, net generation capability under adverse and optimum water conditions, and the estimated average annual potential output for all but the three smallest facilities. This information is recorded in the company's annual reports to the Federal Power Commission (FPC). Montana Power estimates that the ten largest facilities can generate an annual average of 3,212,500 megawatt-hours of hydroelectric power. In comparison, the total annual hydroelectric power actually generated by all thirteen facilities for the years from 1970 to 1976 is listed below (in megawatt-hours):

1970	3,534,234 MWh
1971	3,764,277 MWh
1972	3,693,945 MWh
1973	3,158,577 MWh
1974	3,662,796 MWh
1975	3,663,814 MWh
1976	3,741,731 MWh

Source: Federal Power Commission

Table IV- 20

Montana Power Company--Hydroelectric Facilities

NAME	RIVER	NAME PLATE (MW) RATING	NET CAPABILITY MOST OPTIMUM CONDITIONS (MW)	MOST ADVERSE CONDITIONS	ESTIMATED AVERAGE ANNUAL POTENTIAL OUTPUT - BASED ON PRESENT INSTALLED CAPACITY (MWh)
		SOURCE: FPC, FORM 1, 1976			SOURCE: FPC, FORM 12, 1975
Hauser Lake	Missouri	17	16.5	11	111,000
Holter	Missouri	38.4	49	35	226,000
Black Eagle	Missouri	16.8	18	15	156,000
Cochrane	Missouri	48	50	30	245,000
Marony	Missouri	45	47	28	310,000
Rainbow	Missouri	35.6	35	35	292,000
Ryan	Missouri	48	60	50	450,000
Kerr	Flathead	168	180	175	1,060,000
Thompson Falls	Clark Fork	30	40	22	310,000
Mystic Lake	W. Rosebud	10	11.5	11.5	52,500
Milltown	Clark Fork	3			
Madison	Madison	9	9	9	
Flint Creek	Flint Creek	1.1			

Table IV- 21

Montana Power Company--Reservoir Capacity of Hydroelectric Facilities

NAME	STORAGE ASSOCIATED WITH MAXIMUM DRAWDOWN (Acre/Ft)	GROSS HEAD ASSOCIATED WITH OPTIMUM GEN. CAPACITY (Ft)	USABLE STORAGE CAPACITY (Acre/Ft)	USABLE STORAGE ABOVE SITE (Acre/Ft)
Hauser Lake	62,000	66.8		Hebgen Lake--345,000, Madison--33,000, Canyon Ferry--1,614,740
Holter	82,000	109.0		Hebgen Lake, Madison, Canyon Ferry, and Hauser--66,500
Black Eagle	1,700	51.8		Hebgen Lake, Madison, Canyon Ferry and Hauser, Holter--81,000
Rainbow	1,000	112.25		Same as Above + Black Eagle--1,700
Cochrane	4,500	76.0		Same as Above + Black Eagle and Rainbow--1,000
Ryan	2,800	151.0		Same as Above + Black Eagle, Rainbow, and Cochrane-4,500
Morony	7,900	83.4		Same as Above + Black Eagle, Rainbow, Cochrane, and Ryan--2,800
Kerr	1,217,000	187.0		Hungry Horse--2,980,000
Thompson Falls	15,000	59.7		Hungry Horse--2,980,000, Flathead Lake--1,217,000
Milltown	300	NA		None
Mystic Lake	20,700	1,128		None
Madison	NA	NA	39,000	Hebgen Lake--345,000
Flint Creek	NA	NA	23,300	None (Georgetown Lake at Site)

SOURCE: FPC, FORM 12,1975

Table IV-21 shows the total storage capacity of the reservoirs associated with each facility and the gross head (i.e., pressure) associated with the optimum generating capacity of each facility. In addition, the developed storage above each facility is listed. The amount of storage actually available for generation is often less than the amounts reported because of management of upstream facilities, water conditions in any given year, recreational and environmental considerations, and other factors. MPC's hydroelectric facilities manager reported that the Mystic Lake and Kerr generating facilities and the Hebgen Lake storage reservoir are the only MPC units which have a storage margin. The other eleven units have less than the optimal amount of storage available for the amount of generating capacity installed, and existing generating capacity at these eleven sites is less than the amount which could be installed considering the characteristics and average annual flow of the rivers. All of Montana Power's hydro facilities (except Mystic Lake and Kerr) are run-of-the-river units. In a low-water year they would be operated at full load. There is almost always considerable water spillage caused by inadequate storage capacity. Kerr, as noted above, is an exception. It is normally cycled to correspond with peak demand fluctuations.

The Madison and Flint Creek facilities contribute only a small portion of MPC's hydro generation, but the amount is always somewhat less than maximum because the water is generally managed in accordance with the recreational uses of the Madison River and Georgetown Lake.

In spite of the overall lack of adequate water storage capacity, MPC estimates that the Mystic Lake, Hebgen Lake, Kerr, and Flint Creek-Georgetown Lake storage and accompanying management practices provide an extra 350,000 megawatt-hours of hydro energy annually to the MPC system. An additional estimated 400,000 megawatt-hours is added annually by the upstream storage and management of Canyon Ferry and Hungry Horse reservoirs.

Table IV-22 lists the five major federal hydroelectric projects in Montana with nameplate capacity ratings, reservoir storage data, average load factors, and 1976 net generation. Estimates of average annual generation could be calculated from the load factors and generation capacity. The facilities may be divided into two groups by marketing organization.

Table IV-22

Major Federally Managed Hydroelectric Projects in Montana

NAME	RIVER	OPERATING AGENCY	NAMEPLATE RATING (MW)	RESERVOIR STORAGE CAPACITY (Acre/Feet)	AVERAGE LOAD FACTOR (%)	1976 NET GENERATION (Megawatt-Hours)
Canyon Ferry	Missouri	U.S. Bureau of Reclamation (Dept. of Energy)	51	Gross Total: 1,946,924 Exclusive Flood Control: 104,000 Joint Use Storage: 799,124 Active Conservation: 712,963	≈ 100%	503,508.2
Yellowtail	Big Horn	U.S. Bureau of Reclamation (Dept. of Energy)	252	Gross Total: 1,116,000 Exclusive Flood Control: 259,000 Joint Use Storage: 250,000 Active Conservation: 363,672	≈ 30%	1,099,107.8
Fort Peck	Missouri	U.S. Army Corps of Engineers	165	Gross Total: 18,900,000 Flood Control - Top 1,000,000 Flood Control & Multiple Use - Next 2,700,000 Carry-Over Mult. Use - Next 10,900,000 Inactive Zone - Next 4,300,000	≈ 62%	1,654,968
Libby 1-4	Kootenai	U.S. Army Corps Engineers	420	Gross Total: 5,850,000 Usable for Generation: 4,965,000	≈ 53%	2,146,000
Hungry Horse	S. Fork Flathead	U.S. Bureau of Reclamation (Dept. of Energy)	285	Gross Total: 3,468,000 Usable for Gen. & Flood Control: 3,000,000	≈ 34.2%	1,499,492 Gross Gen.

Canyon Ferry and Yellowtail, operated by the Bureau of Reclamation (now Department of Energy), and Fort Peck, operated by the U.S. Army Corps of Engineers, are located east of the continental divide. Fort Peck and Yellowtail serve loads in the eastern portion of the state. Much of the output from these two facilities also is exported east and south to other states. Canyon Ferry serves U.S. Bureau of Reclamation (USBR) loads located primarily in central and eastern areas of the state. Power from this unit also is sold to MPC. The power from all three facilities is marketed by the Western Area Power Administration (WAPA).

Libby Dam, operated by the U.S. Army Corps of Engineers, and Hungry Horse Dam, operated by the Bureau of Reclamation, are located in northwest Montana. Power from these two units is marketed by the Bonneville Power Administration (BPA) and meets loads primarily located west of the continental divide.

Management of all the federal projects emphasizes flood control, with joint uses such as power generation, irrigation, and recreation and maintenance of minimum stream flow given varying priorities at each individual facility.

Yellowtail is a peaking unit, and its load factor averages about 30 percent. There is not enough water available for it to be operated as a base load unit and still maintain storage requirements. Irrigation in the area is heavily dependent on the water stored in Yellowtail reservoir. Water rarely is spilled at this site.

The opposite situation prevails at Canyon Ferry. Water run-off exceeds the available storage and spills are common in all but the driest years. All water that is released flows directly into Hauser Lake. Irrigation needs are relatively insignificant in relation to the amount of water available. Canyon Ferry is operated at full capacity nearly 100 percent of the time.

Fort Peck has an average load factor of 62 percent, but its operation in any given year is determined by water availability. In 1975, for example, it operated at full capacity (100 percent load factor) all year and water still was spilled, but this situation is the exception rather than the rule. Stream navigation and irrigation are both priority considerations at Fort Peck. However, total consumptive uses of the reservoir is minimal in proportion to the amount of water available.

Hungry Horse is considered a peaking unit. Its average annual load factor for the period from 1954 to 1977 was 34.2 percent, and the average annual generation for the same period was 961,169,166 kilowatt hours. Hungry Horse is one of the furthest upstream units in the Columbia River Base System. Its primary purpose is to maintain adequate storage for downstream generation rather than continuous maximum output from its own generators. Hungry Horse storage is responsible for an estimated 4.6 billion kilowatt-hours (kWh) of energy generated at downstream facilities. Consequently, management decisions determine the amount of water release at Hungry Horse in accordance with power needs throughout the entire Columbia River system. Water rarely is spilled at Hungry Horse; most of it is used to generate power.

Libby also is used primarily for peaking, although it may be operated at base load when a more continuous flow of water is needed at downstream facilities. Libby fills the same basic role of upstream water storage and power generation for the Columbia River Base System as Hungry Horse. Libby's present average annual load factor, based on peak operating capacity, is 53 percent. This will decrease in 1984, however, when Canada's upstream water diversion allowance is scheduled to increase. Based on average water conditions, Libby's present average annual generation is 1,935,960 MW. A re-regulating dam will be added by approximately 1984 which will provide added storage and added control for regulating stream flow. This will provide greater flexibility for the generation facilities to gear up or shut down in response to peak demand fluctuations.

The Flathead Irrigation Project is managed by the Bureau of Indian Affairs. The generation facility provides a minimal amount of power that is used directly by the project. This unit is listed in Table IV-23 with the facilities owned by small utilities or utilities with service areas located primarily outside Montana. Troy and Big Fork are run-of-the-river units which generate power exclusively for local consumption. Noxon Rapids, owned and operated by the Washington Water Power Company, is the only facility of major significance in this table. It may be considered a semi-peaking unit because it is operated by daily load factoring, with generation adjusted according to fluctuations in

Hydroelectric Facilities in Montana Other than Federal

NAME & OWNER	RIVER	NAMEPLATE (MW) RATING	NET CAPABILITY (MW) MOST OPTIMUM CONDITIONS	NET CAPABILITY (MW) MOST ADVERSE CONDITIONS	NET GENERATION 1976-MWh	ESTIMATED AVERAGE ANNUAL GENERATION UNDER MEDIAN WATER CONDITIONS (kWh)
Noxon Rapids Units 1-4 Unit 5 Washington Water Power	Clark Fork	282.8 114	554 (Running at Peak)	334	2,003,921	1,748,715,000
Big Fork Pacific Power & Light	Swan River	4.26	1977 Average Output 2.357		30,621	
Troy Montana Light & Power	Lake Creek	4.5			24,678	
Flathead Irrigation Project U.S. Bureau of Indian Affairs	Big Creek	0.36			2,235	1,988,465 (1975-1977 Average)

demand. Under average water conditions Noxon Rapids can generate an estimated 1,748,715 MWh of power annually. Storage capacity contributes an estimated 387,262 MWh of this total with the remainder, 1,361,453 MWh produced by the natural flow of the river. Peak capacity for all five units is 554 megawatts. Noxon Rapids would operate at 36 percent average load factor to produce the estimated 1,748,715 megawatts noted above. The reservoir at Noxon Rapids is kept full (116,300 ft^3/s per day) except during the spring run-off period. The amount of water available at any given time essentially is regulated by upstream facilities.

The facilities at Noxon Rapids, Libby, Hungry Horse, Kerr, and Thompson Falls are all part of the Columbia River Base System of hydroelectric projects. Water management is coordinated throughout the system, although the power is marketed by the individual owners and marketing agencies.

2. Future Planned Hydroelectric Facilities

Hydroelectric facilities which could be constructed in Montana in the future are listed on Table IV-24. The additional units at Libby are the most likely to be constructed within the indicated time frame. The Kootenai Falls proposal must receive approval under the Montana Major Facility Siting Act. Northern Lights, Incorporated, has contracted with the Montana Department of Natural Resources and Conservation for certain environmental studies. The company has announced that it expects to file a formal application in 1978 and begin construction in 1980. The construction date may be optimistic.

The Buffalo Rapids sites have been under consideration by the Montana Power Company for many years. The sites presently also are being studied by the U.S. Army Corps of Engineers (CE). MPC originally proposed two units totalling 240 MW capacity at each site, or 480 MW total capacity. The CE study contemplates high, run-of-the-river dams at both sites with storage modifications that could increase total capacity closer to 300 megawatts at each site. Both sites are located on the Confederated Kootenai-Salish Indian Reservation. Any future plans must take the tribe's position into account, especially since the tribe has blocked previous proposals. Future hydrogeneration at either of these sites must be considered highly uncertain.

Potential Future Hydroelectric Facilities

Ownership	Name	River	Anticipated Capacity (MW)	Anticipated Year of Construction	Remarks
U.S. Government: Operated by U.S. Army Corps of Engineers	Libby Units 5-8	Kootenai	420	1983	
	Libby Regulating Units 1-4	Kootenai	45.9	1983-84	
Northern Lights, Inc.	Kootenai Falls	Kootenai	140 (150 Run-of-River)	1986	No application for construction has been filed. See text.
	Buffalo Rapids Site 2	Flathead	276		See text.
	Site 4	Flathead	276		
U.S. Government: Operated by U.S. Army Corps of Engineers	Fort Peck (Addition)	Missouri	185		Addition is under study; no specific proposal has been made.
U.S. Government: Operated by U.S. Bureau of Reclamation (DOE)	Canyon Ferry (Addition)	Missouri	90		Addition is under study; no specific construction proposal has been formulated.
Montana Power Company	Thompson Falls (Addition)	Clark Fork	34		No specific proposal has been formulated.

The aforementioned CE study of the Flathead and Clark Fork Rivers was scheduled for release in May 1978. It included studies of 11 possible dam sites, including two on the Blackfoot River. At this point, however, no site in this study appears near the stage of being incorporated into a specific construction proposal.

The CE district office in Omaha, Nebraska, reports that an additional 185 MW of capacity at Fort Peck is presently under study. This new capacity would provide peaking power, but no proposed date of construction has been set. Additionally, the U.S. Bureau of Reclamation is appraising the feasibility of adding 90 MW at Canyon Ferry. If this capacity is added, Canyon Ferry would operate as a peaking unit in the future.

Montana Power soon will add a regulation dam to the Mystic Lake facility. This dam would add approximately 400 acre-feet of storage and would allow MPC to use the facility for peaking power if necessary. Two additional generating units, each 17 MW in size, may be added at Thompson Falls, but this will require Federal Energy Regulatory Commission approval.

3. Loads and Contracts

Utility ownership, federal management responsibilities, load obligations, electric sales data, and service area boundaries are some of the factors which determine the distribution of hydroelectric power for energy consumption in Montana and the western region. When a block of power enters the transmission grid system, it cannot be traced to its generation site or its ultimate destination. However, key transmission routes can be identified and service areas, electric sales, and purchase patterns between utilities and government marketing agencies can be analyzed to provide some understanding of power flows. This section includes a general discussion of load and sales information acquired during this study.

The U.S. Bureau of Reclamation (USBR) and Western Area Power Administration (WAPA) loads served in Montana in 1976 are shown in Table IV-25. Electric cooperatives and irrigation districts are preferred customers and they comprise almost the entire WAPA load in Montana for 1976. It is immediately apparent that the combined amount of power generated at Fort Peck, Canyon Ferry, and Yellowtail far exceeds WAPA's Montana load,

Table IV-25

U.S. Bureau of Reclamation Electricity Sales in Montana in 1976

	(Kilowatt-Hours)
Electric Cooperatives	
Central Montana Electric G & T Coop.	251,352,242
Glacier Electric Coop.	114,241,860
Mid-Yellowstone Electric Coop.	25,497,572
Valley Electric Coop.	15,133,987
Upper Missouri G & T *	251,139,939
Montana Power Company	0
Irrigation Districts	
Buffalo Rapids #1	8,016,000
Buffalo Rapids #2	5,016,000
Intake	57,104
Kinsey	1,932,965
Lower Yellowstone	185,820
Malta-Dotson	111,840
Savage	732,150
Toston	4,308,800
State Water Control Board - Helena	2,213,536
State Water Control Board - Sydney	1,721,683
Three Mile Pump	11,040
U.S. Irrigation Service - Montana	1,851,623
School District #21	44,790
	683,568,951

* This cooperative extends into North Dakota--sales reflect total service area.

Source: Department of Energy, Bureau of Reclamation, Billings, 1978.

although it is somewhat misleading to make such a comparison since all power generated by federal facilities in the WAPA region is pooled to serve the agency's entire load obligation. Nevertheless, WAPA does not import power into Montana, and its exports much of the in-state generation. However, in any given year, especially low-water years, WAPA may purchase power from Montana Power Company (MPC) to meet in-state load requirements. Also, MPC buys power annually from WAPA at both Canyon Ferry and Fort Peck. The USBR (WAPA) transmission system is split electrically between east and west in Montana. Thus, Canyon Ferry serves the western-most portion of WAPA's Montana loads. Power generated at Fort Peck and Yellowtail primarily moves east, although it can be transmitted west from these two facilities. However, a synchronous tie would have to be added to the transmission grid system in order to move power eastward from generation sites located further west, such as Canyon Ferry. This partially explains why excess Canyon Ferry generation is sold on the market rather than transmitted to serve WAPA loads in other states located further east. By approximately 1981 WAPA will provide only a specified amount of power to serve Montana loads. After that time customers will have to purchase power from other sources to meet load increases.

The Bonneville Power Administration (BPA) served the Montana loads listed in Table IV-26 in 1976 and 1977. BPA's situation is somewhat the opposite of WAPA's. Generation from Libby and Hungry Horse goes into the Pacific Northwest Power Pool (PNWPP), but BPA loads in Montana always exceed the generation produced at these two sites. Power from the PNWPP is 80 percent hydroelectric and 20 percent thermal; thus, electric power imported to serve BPA's Montana loads reflects this fuel mix. As shown in Table IV-26, a portion of BPA's load is comprised of preferred customers with firm, long-term contracts; that is, electric cooperatives. Stauffer Chemical and Anaconda Aluminum have non-firm contracts. The volume of BPA's load in Montana may decrease in the near future because the contracts with MPC and Pacific Power and Light (PP&L) presently are on termination notice. PP&L's contract expired in 1977 and MPC's contract will end after 1980. In the future these utilities

Table IV-26

Bonneville Power Administration Electric Deliveries in Montana (1976 and 1977)

	1976 (MWH)	1977 (MWH)
Electric Cooperatives *		
Fall River Electric Co-op.	20,233	23,424
Flathead Electric Co-op.	90,147	101,808
Lincoln Electric Co-op.	50,327	51,916
Missoula Electric Co-op	81,110	93,689
Northern Lights Electric Co-op.	22,844	24,101
Ravalli County Electric Co-op.	58,481	65,641
Vigilante Electric Co-op.	67,235	76,400
Industries **		
Anaconda (Aluminum) Co.	2,778,654	2,851,156
Stauffer Chemical Co.	438,466	449,583
Federal Agencies		
Flathead Irrigation Project (BIA)	69,763	109,425
Private Utilities		
Montana Power Company	880,464	516,710
Pacific Power and Light Company	101,942	141,929
	4,659.666	4,505,782

Source: BPA Regional Office, Kalispell

* Cooperative deliveries include power made available through the Columbia Storage Power Exchange which manages Canada's share of hydro-power for use in the U.S.

** Figures include industrial replacement energy.

will be able to purchase only surplus power from BPA on a case by case or emergency basis. After 1980, BPA will begin selling at least part of the power withdrawn from MPC to Glacier Electric Cooperative. The USBR (WAPA) presently supplies this cooperative. USBR (WAPA will subsequently be able to meet load growth demands for Central Montana G & T Electric Cooperative with the power released from commitment to Glacier Electric.

Montana Power Company controls the BPA power sold to the electric cooperatives. The two points of power exchange between the BPA and MPC transmission systems are at Anaconda, Montana, and Hot Springs, Montana. There also is a connection at Kerr Dam, but power is not actually exchanged there.

BPA controls electrical power in Montana for both PP&L and Washington Water Power Company (WWP). These two utilities reflect an opposite balance of load obligations and generating capacity in Montana. WWP owns and operates Noxon Rapids, but it has no Montana loads. The Federal Power Commission (FPC) data indicate that in any given year, WWP sells power to and buys power from MPC in Montana for resale. The amount sold to MPC may be greater or lesser than the amount purchased, depending on the year. WWP also has both sale and purchase transactions with Utah Power and Light Company in Montana in any given year which usually exceed the volume of MPC transactions. In reality, most of the output from Noxon Rapids probably is utilized by MPC customers or transmitted south for Utah Power and Light Company; but in terms of ownership, it goes into the Pacific Northwest Power Pool (PNWPP) and is used to meet WWP loads in Washington.

Pacific Power and Light Company (PP&L), on the other hand, has a sizable load in the portion of its service area located in Montana. However, with the exception of the small facility at Big Fork which serves the Big Fork area, PP&L has no hydroelectric facilities in Montana. Thus, PP&L must import power from the PNWPP. PP&L has historically purchased power from BPA in Montana. FPC data indicate that this amount is only a fraction, perhaps one-quarter, of the total kilowatt hours PP&L sells for direct consumption in Montana. As noted above, PP&L's firm power contract with BPA has expired. Unless BPA has surplus power available in the future, PP&L will be forced to import more power

or perhaps purchase power from MPC. According to FPC data, past transactions between MPC and PP&L have been minimal.

Montana-Dakota Utilities Company (MDU) serves the far eastern portion of Montana. MDU has no hydroelectric facilities, but its Lewis and Clark coal-fired plant is located in Montana. MDU has only two transmission lines in Montana which carry significant blocks of power, and both are connected to the USBR transmission system.

Montana Power Company's (MPC) annual electric sales and purchase reports to the Federal Power Commission (FPC) were reviewed for selected years from 1964-1975. The largest and most consistent energy transfers across state lines are from MPC to Utah Power and Light Company. In 1975, for example, MPC sent 748,782 MWh to Utah Power and Light. The transmission lines from Anaconda, Montana, to Monida, Idaho, and points south were constructed primarily to accommodate this on-going transfer of electricity. MPC also delivers power to Idaho Power and Light Company, primarily for consumption in the Salmon, Idaho service area. Both sale and purchase transactions between MPC and WWP, BPA, and USBR occur annually. Only purchases from USBR are reported for Canyon Ferry while both purchases and sales between MPC and USBR are delivered at Fort Peck. The specific volume of these transactions is not included in this report.

4. Thermal Electric Facilities in Montana

There presently are six active thermal electric units in Montana. Of the six, five are owned and operated by the Montana Power Company (MPC) and one is owned by Montana-Dakota Utilities (MDU).

Table IV-27 lists the existing and proposed thermal electric facilities in Montana. This table gives the location, ownership, nameplate rating (MW), and type of fuel used. With the exception of MPC's Bird facility, all of the facilities utilize coal and are used for baseloads. MPC utilizes the Bird facility for peaking power only because of the very high fuel costs associated with oil and natural gas.

The average service stream (i.e., the actual time available for production in the coal-fired generating facilities) is approximately 82 percent. Using this figure, the annual average output for the coal-fired

Table IV-27

Existing Thermoelectric Facilities in Montana

PLANT	LOCATION	OWNERSHIP	CAPACITY (MW)	FUEL
BIRD	BILLINGS	MPC	60 PEAK	OIL/GAS
CORETTE	BILLINGS	MPC	173 BASE	COAL
COLSTRIP 1	COLSTRIP	MPC	330 BASE	COAL
COLSTRIP 2	COLSTRIP	MPC	330 BASE	COAL
LEWIS & CLARK	RICHLAND COUNTY	MDU	50 BASE	COAL
Proposed Thermoelectric Facilities in Montana				
COLSTRIP 3	COLSTRIP	MPC et al.	770 BASE	COAL
COLSTRIP 4	COLSTRIP	MPC et al.	770 BASE	COAL
UNNAMED	UNKNOWN	MPC	350 BASE	COAL

thermal facilities is approximately 6,342,000 MWh of electrical power.

Currently proposed additions to the thermal electric facilities in Montana are Colstrip Units 3 and 4, each having a 770 MW nameplate capacity, and one additional coal-fired facility having a rating of 350 MW. The proposed facilities at Colstrip would be owned by a consortium of northwest utilities including Pacific Power and Light (20 percent), Puget Sound Power and Light (25 percent), Portland General Electric (15 percent), Washington Water Power (10 percent), and Montana Power Company (30 percent). Additionally, 10 percent of the productive capacity is revised for Rural Electric Cooperatives, should they choose to participate. If this occurs, the principal partners will maintain their respective percentages of the remaining power generated. The percentage of power available to Montana utilities (MPC and PP&L) would be 50 percent or approximately 5,000,000 MWh per year. The amount which would remain in Montana is unknown because of the interstate operation of PP&L. The proposed 350 MW coal-fired plant to be owned by Montana Power would have an addition of 2,500,000 MWh per year.

The legal status of the proposed plants is uncertain. The proposed plants at Colstrip have met with strong opposition and have been denied permits by the U.S. Environmental Protection Agency (EPA). This ruling is being appealed by the utility consortium, and the outcome of this appeal is unknown. The unnamed, proposed 350 MW plant has not yet begun the permit application process and siting procedure; therefore, its future is totally unknown.

Other sources of thermal electric power for Montana include contributions by MDU and PP&L thermal plants located outside Montana, notably in Wyoming.

The future for thermal electric facilities utilizing nuclear power in Montana is doubtful. Montana passed a public initiative in November 1978 (Initiative 80) which places strong restraints on the development of the nuclear industry. Industry officials state that these restrictions are totally prohibitive of nuclear development.

5. Transmission Line Carrying Capacities

Data on the carrying capacity of transmission line have been collected for lines in Montana of at least 115 kilovolts or greater voltage. Montana Power Company (MPC) lines of 69 and 100 kV voltage also are included. Lines used to transfer significant blocks of power within the region and across state lines and tie lines connecting utility and federal agency systems are emphasized. The data are presented in three tables (Tables IV-28 through IV-30) which represent the U.S. Bureau of Reclamation (USBR) system, the Bonneville Power Administration (BPA) lines, Pacific Power & Light Company (PP&L), Washington Water Power Company (WWP), and Montana-Dakota Utilities (MDU) lines. The line carrying capacities are presented in megavolt amperes (MVA).

The MVA rating is not precisely equivalent to the amount of megawatts that can be carried over a line unless there is no load impedance. In order to precisely calculate megawatt carrying capacity, it would be necessary to know the electrical characteristics of the load being served as well as any specific limiting factors in the sytem design which reduce the capacity of any given line segment. Specialized studies would be required to make these calculations. However, the MVA data in the tables have been adjusted for various types of system limitations. In most cases the limiting factor is noted. Engineers from BPA and USBR have stated that the MVA ratings for each line segment closely approximate the load capacity, although under actual system conditions the load transferred through the lines is always somewhat less than the amounts stated.

The primary reason for gathering this data is the identification of the lines which tie utility and federal agency systems together. In many cases a switchyard serves as the point of interchange. Therefore, the carrying capacities of the lines leading into certain switchyards are important. Additionally, some lines cross state boundaries. The power is transferred to another utility either at the border or a specified metering point. Table IV-31 presents voltage line length and MVA data for all the tie lines, and lines leading into substations which

Table IV-28

U.S. Bureau of Reclamation Transmission System*

LINE	VOLTAGE (kV)	LENGTH (MILES)	CAPACITY (MVA)	LIMITING FACTORS
Custer - Yellowtail	230	61.2	160	Current Trans.
Dawson - Dickinson, N.D.	230	111.0	399	Wave Tap
Yellowtail - PPL Switchyard	230	0.9	412	Relay Limitati
Fort Peck - Dawson Co.	230	105.0	202	Relay Limitati
Dawson Co. - Custer	230	160.2	160	Relay Limitati
Fort Peck - Richardson Coulee	161	24.9	60	Transformer
Richardson Coulee - Harlem	161	112.3	110	Current Trans.
Harlem - Havre (Asbn)	161	51.1	110	Current Trans.
Havre - Rainbow	161	103.0	60	Transformer
Yellowtail to Lovell, WY.	(2) 115's	46.0	80	Current Trans.
Havre - Rudyard	115	32.9	38	Current Trans.
Rudyard - Tiber Tap	115	27.8	116	Summer Limit
Tiber Tap - Shelby	115	37.8	80	Wave Tap
Tiber - Tiber Tap	115	11.9	2	Transformer
Circle - Dawson Co.	115	45.7	40	Current Trans.
Circle - Wolf Point	115	53.8	40	Operating Limi
Fort Peck - Wolf Point 1	115	35.7	40	Current Trans.
Fort Peck - Wolf Point 2	115	35.8	80	Wave Tap & Current Trans
Wolf Point - Poplar	115	27.3	80	Current Trans.
Poplar - Williston	115	66.7	80	Current Trans.
Miles City - O'Fallon Cr.	115	45.6	20	Current Trans.
O'Fallon Cr. - Dawson Co.	115	26.0	40	Current Trans.
Dawson Co. - Lewis & Clark	115	48.9	80	Wave Trap
Dawson Co. - Glendive	115	2.7	79	Summer Limit
Richland - Lewis & Clark	115	0.1	120	Disconnect Swi
Richland - Williston	115	43.0	80	Wave Trap
Canyon Ferry - East Helena A	100	7.5	52	Current Trans.
Canyon Ferry - East Helena B	100	7.5	52	Current Trans.

* The MPC System Data Book reports two 115 kV lines belonging to USBR between Shelby and Cut Bank and Browning, but USBR shows local co-op ownership for these lines.

Source: MAPP Operating Handbook.

Table IV-29

Bonneville Power Administration
Transmission Line Capabilities

LINE	VOLTAGE (kV)	LENGTH (Mile)	RATING (MVA)
Anaconda-Silver Bow (Stauffer Chem.)	115	12.7	120
Bell* - Noxon	230	96	478
Bonners Ferry - Troy	115	30.2	92
Columbia Falls - Kalispell	115	10.8	68
Columbia Falls - Trego	115	46	92
Conkelley - Flathead (Anaconda Co)	230	16.4	359
Flathead - Hot Springs	230	56.5	359
Hot Springs - Anaconda	230	146.5	359
Hungry Horse - Columbia Falls	115	8.2	68
Hungry Horse - Conkelley (Anaconda Aluminum)	230	6.9	359
Kalispell - Kerr	115	41.4	68
Libby - Conkelley (Anaconda Aluminum)	230	83.9	478
Libby - PP&L Libby	230 115	12.3 12.3	235 118
Noxon - Hot Springs	230	67.5	478
Noxon - Libby	230	70.2	478
Hot Springs - Dworshak	500	142.6	1853
Hot Springs Sub.	500 230	0.1 0.1	2598 1195
Libby Ph. 1 2	230 230	13.5 13.5	602 602

* Bell Substation is Near Spokane.

Table IV-30

Transmission Line Carrying Capacity

PACIFIC POWER & LIGHT COMPANY

kV	LINE	LENGTH	MVA
230	Yellowtail to Muddy Ridge, WY	175.77	397
230	Yellowtail to Casper, WY	169.99	310
161	Billings to Yellowtail	86.76	173
230	Sheridan, WY to Decker	13.86	*
115	Libby to Troy (BPA Switch Sta.)	17.0	77.4

WASHINGTON WATER POWER COMPANY

kV	LINE	LENGTH	MVA
230	Noxon Plant to BPA 230 Line	0.8	
230	Noxon Plant to BPA at Hot Springs	70.01	480
230	Noxon Plant to Pine Creek Sub.	42.27	410
230	Cabinet Gorge to Noxon	18.51	360

MONTANA - DAKOTA UTILITIES **

kV	LINE	LENGTH	MVA
115	Glendive - Baker	55.9	30
115	*** Williston - Plentywood	80.0	30

* Connected to Yellowtail-Casper and limited by that line's capacity, but has same conductor as Muddy Ridge Line and can equal that line's capacity when power is flowing opposite ways through those two lines.

** Both lines connect to USBR facilities. The lines' maximum rating is 97 MVA but voltage drop problems allow only 30 MVA capacity to the utilized. Also, MDU has numerous smaller lines of ≈34.5 kV but these serve only local loads and are not used to transfer significant blocks of power.

*** Presently operated at 57 kV but will be upgraded; partially owned by local cooperative.

Table IV-31

Principal Tie or Connecting Lines

LINE	LOCATION	kV	LENGTH (Miles)	CAPACITY	LIMITING FACTOR
BPA-MPC-WWP Systems					
Anaconda BPA Sub to Mill Creek Sub. (MPC)	Anaconda	230	0.4	478 MW*	
Hot Springs to Ovando (MPC)	Hot Springs	230	89.7	478 MW*	Relay Settings
Hot Springs to Anaconda (BPA)	Hot Springs	230	146.5	359 MVA	
Noxon to Hot Springs (BPA)	Hot Springs	230	67.5	478 MVA	
Hot Springs to Dworshak, ID (BPA)	Hot Springs	500	142.6	1853 MVA	
Noxon to Hot Springs (WWP)	Hot Springs	230	70.01	480 MVA	
Kerr to Rattlesnake A (MPC)	Kerr	161	56.1	125 MW*	Voltage Drop
Kerr to Rattlesnake B (MPC)	Kerr	161	57.0	125 MW*	Voltage Drop
Kalispell to Kerr (BPA)	Kerr	115	41.4	70 MW	

* Compare Schedule 18B (Table A) with MPC System Data Book (Table A).

Table IV-31 (Cont'd)

LINE	LOCATION	kV	LENGTH (Miles)	CAPACITY	LIMITING FACTOR
USBR-MPC Systems					
Havre-Rainbow (USBR)	Rainbow Switchyd**	161	103.0	60 MVA***	Transformer
Rainbow-Assiniboine (MPC)	Rainbow Switchyd	161	93.7	80 MW ***	Voltage Drop
Havre-Harlem (USBR) +	Havre	161	51.1	110 MVA***	Current Transform e
Yellowtail to PP&L Yellowtail Swtchyd (USBR)	Yellowtail	230	0.9	412 MVA	Relay Limits
Yellowtail to Lovell, WY (USBR)	Yellowtail	(2) 115's	46.0	80 MVA	Current Trans.
PP&L Switchyard to Billings (MPC)	Yellowtail	230	41.3	450 MW ***	Relay Settings
Yellowtail to Billings (PP&L)	Yellowtail	161	47.0	120 MW	Relay Settings
Yellowtail to Casper, WY (PP&L)	Yellowtail	230	169.9	310 MVA	Summer Limit
Yellowtail to Muddy Ridge, WY (PP&L)	Yellowtail	230	175.77	397 MVA	Summer Limit
Canyon Ferry to Canyon F. Tap (USBR)		(2) 100's	7.5	52 MVA @	Current Trans.
Canyon Ferry Tap to Butte (MPC)		(2) 100's	69.2	91 MVA @	
Canyon Ferry Tap to Great Falls 230 Sub (MPC)		100	64.4	40 MW ***	System Stability
Canyon Ferry Tap to Rainbow "A" (MPC)		100	60.8	40 MW ***	System Stability

** The Rainbow Switchyard is connected by a 100 V line with 130 MW carrying capacity to the Great Falls 230

+ This line extends through Richardson Coulee to Ft. Peck with a 60 MVA capacity limit (transformer).

*** Compare Schedule 18B (Table A) with MPC System Data Book (Table A).

Table IV-31 (Cont'd)

LINE	LOCATION	kV	LENGTH (Miles)	CAPACITY	LIMITING FACTOR
Ft. Peck to Whatley USBR (USBR)	Whatley	69	14.10	63 MVA	
Whatley USBR to Whatley (USBR)	Whatley	69	0.3	41 MVA	
Havre to Whatley (MPC)	Whatley	69	174.1	22 MVA ++ (Portions)	

++Compare Schedule 18B (Table A) with MPC System Data Book (Table A).

serve as points of interchange between utility systems. Table IV-32 contains similar information for the lines which cross Montana's boundaries. All data in these two tables are extrapolated from Tables IV-28 through IV-30.

The BPA and MPC systems connect through a tie line at the Mill Creek substation near Anaconda, Montana, at the Hot Springs substation, and at Kerr Dam. Power is not actually exchanged at the Kerr site. At Anaconda a short 230 kV tie-lines makes the connection while at Hot Springs the switchyard itself serves as the point where BPA, MPC, and WWP lines come together. The various 230 kV lines extending west from Hot Springs and the 500 kV Hot Springs-Dworshack line are the principal lines carrying power between Montana and the Pacific Northwest.

The U.S. Bureau of Reclamation (USBR) system extends west from Ft. Peck to Shelby and Great Falls and south and east from both Ft. Peck and Yellowtail hydroelectric units into Wyoming and the Dakota's. Also, there are two short USBR lines connecting Canyon Ferry to the MPC transmission system. The Rainbow substation at Great Falls, the Havre substation, and the Yellowtail switchyard are the most significant points of interchange. The bureau reports that the carrying capacity of the 161 kV line extending west from Ft. Peck is limited by both transformer capacity and voltage drop problems. Three USBR lines carry power into the MDU system in North Dakota and points further east, and twin 115 kV lines extend south from Yellowtail into Wyoming.

PP&L has three important lines in eastern Montana which converge at PP&L's Yellowtail switchyard. PP&L has no loads in eastern Montana. The lines are connected to PP&L's thermal generating facilities in Wyoming and serve as interties to bring the power into the grid system. MPC and BPA control power westward for PP&L.

6. Loads

An attempt to model electrical energy supply for the state of Montana as a whole is complicated by two overlapping divisions of the state for electrical energy planning and supply purposes, one geographical and the other by power company. The geographical split following the Continental Divide marks a division between two sources of federal

Table IV -32

Principal Lines Connecting Outside Montana

OWNERSHIP	LINE	kV	LENGTH (Miles)	MVA	LIMIT FACTOR
BPA	Bell Sub. to Noxon (Spokane, WA)	230	96	478	
BPA	Hot Springs to Dworshak	500	60 Mi (MT)	1853	
WWP	Noxon to Pine Creek Sub.	230	42.27	410	
WWP	Cabinet Gorge to Noxon	230	18.51	360	
UPL (MPC, IPL, PP&L)	Mill Creek to Antelope, ID	230	73.3 (124.2)	478* (300 MW)	System Stability
MPC	Crow Creek Jct. to Idaho St. Line A B	100 100	8.6 8.6	70 (MW)* 70 (MW)*	System Stability System Stability
MPC (UPL)	Dell to Jefferson, Idaho	161	27.5 (86.2)	167 (174)*	
MPC	Dillon-Salmon to Salmon Meter	69	16.7	35 MVA*	
IPC	Salmeter to Salmon, Idaho	69	52.90	40 MVA*	
PPL	Yellowtail to Casper, Wyoming	230	169.99	310 MVA	Summer Limit
PPL	Yellowtail to Muddy Ridge, WY	230	175.77	397 MVA	Summer Limit
USBR	Yellowtail to Lovell, WY	115 #1 115 #2	45.93 46.0	80 80	Current Transforme Current Transforme
USBR	Dawson to Dickerson	230	[illegible]	399	Wave Trap

* Compare Schedule 18B (Table A) with MPC System Data Book (Table A).

hydroelectricity: the Bonneville Power Administration (BPA) in the west and the U.S. Bureau of Reclamation (USBR) in the east. Overlapping the geographical is the division of the state into the Montana Power Company (MPC) service area and the remainder of the state. Since MPC serves 70 percent of the utility-type load in the state and also is planning entity in its own right, it merits special consideration.

In order to choose an appropriate model for the state, it is necessary to understand the characterization and location of electrical loads in the state and the supply sources which meet those loads. The following text is an effort to assemble and reconcile statistics from a variety of sources to achieve such a characterization.

Montana, west of the Continental Divide, lies in the Columbia River drainage and is, therefore, a part of the BPA region. With the exception of MPC's service area, supply planning for the west is done as part of the West Group of the Pacific Northwest Utilities Conference Committee. Electric cooperatives in the region are West Group loads, as is Pacific Power & Light Company (PP&L). One large BPA direct-service industrial customer, the Anaconda Aluminum Smelter at Columbia Falls, is also in the region; because its presence has a distorting effect on the region and the state, it will be dealt with first.

The figures in Table IV-33 suggest that the Columbia Falls aluminum load is in the West Group industrial load. This is not an unreasonable conclusion, as the remainder of the West Group loads are dominated by co-operatives serving largely rural areas, the principal exception being PP&L's service area. The aluminum load is unique in several respects. It is different in character from loads typically served by utilities, and indeed as a BPA direct customer, it is not a utility load. Furthermore, the aluminum reduction load in BPA's region is met largely with secondary, non-firm hydro energy resulting from streamflows above the critical water assumption used for long-term planning purposes. This energy may or may not be available in any given year. All this indicates the desirability of separating the aluminum load from other "utility-type" loads for planning or modeling purposes, and Table IV-33 suggests an approximation to this by equating the West Group industrial load to aluminum reduction load.

Table IV -33

Comparison of West Group Industrial and SIC 33 Loads in Montana (GWh)*

	1974	1975
West Group Industrial	3811	2856
SIC 33, Primary Metals	3829	2942

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* GWh is gigawatt-hours, or 1.0 x 10^9 watt-hours.

Table IV-34 represents such a separation, as well as a geographical separation into west and east of the Continental Divide. Additionally, it proves instructive to look at a further breakdown of loads into industrial and nonindustrial (mainly residential and commercial) loads. In Table IV-34, line 1 shows statewide figures, as reported by Edison Electric Institute. Lines 2 and 4 are from BPA data for Montana west of the Divide and for West Group loads only; line 3, for the east, is the difference of lines 1 and 2. Lines 5 and 6 exclude all West Group loads; lines 7 and 8 exclude only the West Group industrial load, and thus by the argument above approximate utility-type loads for the west and for the whole state, respectively. (Line 3, for the east, is all utility-type.)

Inspection of this table provides several interesting observations, particularly regarding the location of industrial loads. Although utility loads in Montana are 37 percent industrial (line 8), the figure west of the Divide is 45 to 50 percent (line 7), and no more than 31 percent industrial east of the Divide (line 3). Comparable figures are 38 percent industrial for the entire U.S., 40 percent for Oregon, and 44 percent for the entire West Group. Strictly speaking, the last two figures include aluminum reduction and thus should be compared to line 1 of Table IV-34, which shows some 57 percent or more industrial load in Montana. But the wholly disproportionate position of the aluminum load in Montana--35 to 40 percent of the total load--make the other comparisons more meaningful.

Since West Group loads in Montana are only a small part (3.5 percent total, 1.2 percent non-industrial) of the entire West Group, it is important to note by comparing lines 5 and 8 of Table IV-31 that no more than 12 percent of Montana utility-type loads are served from the West Group. That is, Montana is a small part of the West Group, and--except for the aluminum load--the West Group serves a relatively small portion of Montana.

Table IV-35 shows the situation in somewhat different form for two recent years, for the utility-type (non-aluminum) load only. The left side is a rearrangement of data from Table IV-34; the right side is an attempt to attribute load to particular utility groups. These figures

Table IV-34

Montana Loads by Region and Class (GWh)

		1970	1971	1972	1973	1974	1975
) Montana	Industrial	6120	6079	5888	5031	5963	5089
	Non-Industrial	2971	3135	3303	3541	3577	3778
	Total	9091	9214	9191	8572	9540	8867
) West	Industrial	4973	4772	4957	4521	5119	4026
	Non-Industrial	984	1071	1167	1272	1298	1399
	Total	5957	5843	6124	5793	6417	5425
) East	Industrial	1147	1307	931	510	844	1063
	Non-Industrial	1987	2064	2136	2269	2279	2379
	Total	3134	3371	3067	2779	3123	3442
) West Group	Industrial	3782	3713	3769	3232	3811	2856
	Non-Industrial	465	517	570	635	647	710
	Total	4247	4230	4339	3867	4458	3566
5) Non-West Group	Industrial	2338	2366	2119	1799	2152	2233
	Non-Industrial	2506	2618	2733	2906	2930	3068
	Total	4844	4984	4852	4705	5082	5291
6) West, Non-West Group	Industrial	1191	1059	1188	1289	1308	1170
	Non-Industrial	519	554	593	637	651	689
	Total	1710	1613	1781	1926	1959	1859
7) West, less WG Industrial	Industrial	1191	1059	1188	1289	1308	1170
	Non-Industrial	984	1071	1167	1272	1298	1399
	Total	2175	2130	2355	2561	2606	2569

Table IV-34 (Cont'd.)

		1970	1971	1972	1973	1974	1975
8) Montana, less WG Industrial	Industrial	2338	2366	2119	1799	2152	2233
	Non-Industrial	2971	3135	3303	3541	3577	3778
	Total	5309	5501	5422	5340	5729	6011

Table IV-35

Estimated Utility-type (non-aluminum) Load (GWh)

		Industrial	Non-Industrial	Total	Co-Ops	PP&L	MDU	MLP	MP
	West Group	--	647	647	365	282			
	Other West	1308	651	1959				50	1909
1974	West of Divide	1308	1298	2606					
	East of Divide	844	2279	3123	600		400		2123
	Montana	2152	3577	5729		1697			4032
	West Group	--	710	710	400	310			
	Other West	1170	688	1858				50	1808
1975	West of Divide	1170	1398	2568					
	East of Divide	1063	2380	3443	600		400		2443
	Montana	2233	3778	6011		1760			4251

are not hard data, but are estimates chosen to produce totals in agreement with those to the left. The figure shown for Montana-Dakota Utilities is especially suspect due to the unavailability of data which would separate that utility's load by states. The dominant position of Montana Power, some 70 percent of all utility-type load, is revealed clearly regardless of these evident shortcomings in the data.

It is important to note, however, that this dominant utility is not characteristic of the utility loads in the state as a whole. The company serves an unusually high proportion of industrial load--some 50 percent of the total company load. Since this is very close to the total (non-aluminum) industrial load in the state, as Table IV-35 shows, it is evident that other utilities combined have very little industrial load, probably less than ten percent of their total loads. Thus, Montana Power is a highly atypical utility, even though utility loads in Montana as a whole appear to be apportioned reasonably closely to national averages for the different customer classes.

7. Analysis and Conclusions

Montana as a whole, disregarding the Columbia Falls aluminum plant, has load characteristics not far removed from typical utility type loads. On a regional basis, however, Montana west of the Divide is characterized by a disproportionately large industrial load component; east of the Divide the industrial component is disproportionately small. Montana Power Company, which serves 70 percent of the state's utility load, has company characteristics quite similar to western Montana. Although only 45 percent of the company's load is in the west, the absence there from its service area of loads (overwhelmingly non-industrial) served by West Group utilities offsets the company's larger non-industrial component in the east, to give it overall a 50 percent industrial load mix. This mix results in a very high average annual load factor of 0.70 for the company and hence a quite flat annual load duration curve, a characteristic that would not hold for utility loads in the state as a whole. Therefore, although Montana Power is in fact serving as the major supplier for new thermal generation in the state, its peculiar load characteristics preclude taking its company requirements

as a fair model for the state as a whole.

The presence or absence of the Anaconda aluminum load has virtually no effect on generation planning or costs for Montana utility-type load. Were it to disappear, the result would be a reallocation of West Group resources, with little or no direct effect on Montana. Furthermore, the 12 percent of Montana utility-type load served by West Group utilities can be expected to have a future cost experience quite similar to the balance of the state, since the two entities are going through essentially parallel transitions to baseload thermal generation.

8. Electrical Model

Given the supply and load configurations existing within the state, the modeling procedure used for electrical power in the Montana Energy Model follows:

- To model only utility type loads (both industrial and non-industrial) and assume the increases in these loads subject to the variables in the energy demand submodel;
- To assume all increased electrical generation to be coal-fired thermal facilities of 250 megawatt capacity, and baseloaded for production;
- To assume peak generation loads to be 55 percent of the annual generation; and
- To add the aluminum reduction load into the total load for the period 1978 to 1987 in order that the employment and demographic models can assess the impacts of aluminum production in Montana; but after the year 1987 the aluminum load is not considered.

The last parameter appears reasonable in the face of rapidly increasing transportation costs and changes in the reduction process working together to reduce the economic advantage of cheap electricity presently available in Montana. The Anaconda aluminum contract with BPA also ends in 1987 and current estimates indicate that all BPA resources will be committed elsewhere at that time.

The algorithm used for the mathematical modeling of electrical supplies is a linear programming method. Linear programming is a mathematical technique where an objective function is minimized or maximized, subject to a number of constraint equations. The general

mathematical form is

$$\text{Minimize} \sum_{j=1}^{P} c_j x_j \text{, subject to} \qquad \text{(Eq. IV-2)}$$

$$\sum_j \frac{1}{e_{ij}} x_j \leq S_u \text{, where}$$

$u = 1 \ldots n_j$; and

$\Sigma_j d_{vj} x_j = D_v$, where

$v = 1 \ldots m$; and

$x_j \geq o$.

The goal of this equation is to minimize the sum of the costs of electricity from source x_j at cost c_j subject to the constraints that the sum of the electricity from source x_j times a load factor for the facility e_j cannot exceed the production capacity of the facility; the sum of the demands of type d_{vj} times the resource x_j must equal the demand for all resources. All sources of supply must be equal or greater than zero, a mathematical necessity for the algorithm. On an intuitive basis,it simply states that no source (x_j) can have a negative contribution to electrical supply.

There are four basic types of constraint equations in the electrical supply model. They are supply, capacity, demand, and peaking and balance equations.

a. Supply Equations

Supply equations limit the amount of any given resource which may be used at a given point in time.

b. Capacity Equations

Capacity equations limit the generating capacity of certain types of plants. This is of particular importance to hydroelectric facilities where there is a finite number of potential sites for hydroelectric production. Coefficients in the capacity equation depend upon load factors and plant factors; these are defined below.

Load factors represent demand duration. The load factor is a ratio of peak demand to total demand for the respective facility. The plant factor is defined similarly as the service stream available from a given facility. At best, no facility can produce at a factor exceeding unity, but in reality there are maintenance requirements, both scheduled and unscheduled, which reduce the plant availability to some lesser quantity. The electrical supply submodel allows a maximum plant factor of 0.8. This is representative of the history of production in Montana.

c. Demand Factors

Demand equations address the efficiency at which the electricity is converted to final demand. For example, there are efficiencies to be considered in the transmission of electrical power from the point of generation to the ultimate user. Demand equations also can be used to simulate changes in consumption technology.

d. Peaking and Balancing Equation

Peaking and balance equations are necessary when attempting to model the electrical component of the model. Peak demands are random and cannot be entirely eliminated even with greatly improved load scheduling. The peaking equation forces the model to generate at least a portion of peak load with devices specifically designed for peaking power production (e.g., fuel cells, gas turbines, etc.). These peaking facilities will have a load factor of about 0.1. Balance equations maintain an optimal mix between facilities designed for base loads, intermediate loads, and peaking device loads.

REFERENCES FOR APPENDIX A, SECTION IV

A. Coal

Kuntz, Gail, Final Report of Western Coal Demand Research Project, prepared for Montana Energy and MHD Research and Development Institute, Inc., Butte, Montana, January, 1978.

Montana University Coal Demand Study Team, Projections of Northern Great Plains Coal Mining and Energy Conversion Development, 1975-2000 A.D., NSF/RANN Grant No. AER-75-14178, Missoula, Montana, May 1976.

Wheeling, Terry, Coal Demand Scenarios for the Montana Energy Model, The Montana Energy and MHD Research and Development Institute, Inc., Butte, Montana, May, 1978.

Yabroff, Irving and Edward Dickson, A Briefing on the Impacts of the National Energy Plan on Regional Coal Production, Stanford Research Institute, Center for Resource and Environmental Systems Studies, CRESS Report No. 34, Palo Alto, California, September 1977.

B. Oil

Bonner and Moore Associates, Incorporated, Petroleum Supply Alternatives for the Northern Tier States, Volume III, Addendum B--Transportation, Houston, Texas, 1976.

Continental Pipeline Company, Annual Report to the Interstate Commerce Commission for 1975, Schedule 400, Ponca City, Oklahoma, 1976.

Exxon Pipeline Company, Annual Report to the Interstate Commerce Commission for 1975, Schedule 400, Houston, Texas, 1976.

Farmer's Union Central Exchange, Incorporated, Monthly Pipeline Report to the Montana Public Service Commission, Laurel, Montana, January to December, 1975.

Polzin, Paul E., Montana's Major Energy Transportation Systems, prepared for Montana Energy Advisory Office, Helena, Montana, 1976.

Rockler, Elliot, A Report on the Oil Supply Situation in Montana, prepared for the Montana Energy and MHD Research and Development Institute, Inc., Butte, Montana, 1978.

U.S. Geological Survey, Geological Estimates of Undiscovered Recoverable Oil and Gas Resources in the United States, Geological Survey Circular 725, prepared for the Federal Energy Administration, Arlington, Virginia, 1977.

B. Oil (Cont'd)

Yellowstone Pipeline Company, Annual Report to the Interstate Commerce Commission for 1975, Schedule 400, Ponca City, Oklahoma, 1976.

Yellowstone Pipeline Company, Monthly Pipeline Report to the Montana Public Service Commission, Houston, Texas, January to December 1975.

C. Gas

Frizzell, Tom, Montana's Natural Gas Supply Crises, Environmental Quality Council staff report, Helena, Montana, November 1976.

Ibrahim, Maher, Undiscovered Natural Gas Resources of Montana, Montana Energy Advisory Council, Helena, Montana, July 1976.

Itami, Rick, Montana Historical Energy Statistics, Montana Energy Office, Helena, Montana, February 1978.

Kuntz, Gail, Montana Natural Gas Supply, prepared for the Montana Energy and MHD Research and Development Institute, Inc., Butte, Montana, January 1978.

McElwain, Joe, President, Montana Power Company, Testimony to Montana Public Service Commission, Docket No. 6454, Helena, Montana, October 21, 1977.

Oil and Gas Conservation Division, Annual Report - 1976, Montana Department of Natural Resources and Conservation, Helena, Montana, 1977.

National Energy Board of Canada, Annual Report - 1977, Ottawa, 1978.

Nybo, James H., and Terry Wheeling, Montana's Natural Gas Situation and MEAC's Energy Conversion Policy Study, Montana Energy Advisory Council, Helena, Montana, June 1976.

U.S. Geological Survey, "Geological Program to Provide a Characterization of Tight, Gas-Bearing Reservoirs in the Rocky Mountain Region," Proceedings, Third Energy Research and Development Administration Symposium on Enhanced Oil and Gas Recovery and Improved Drilling Methods, Vol. 2--Gas and Drilling, The Petroleum Publishing Company, Tulsa, Oklahoma, 1977.

Wheeling, Terry, Montana Historical Energy Statistics, Montana Energy Advisory Council, Helena, Montana, September 1976.

Wheeling, Terry, Consumption of Natural Gas and Electricity in Montana, Montana Energy Advisory Council, Helena, Montana, 1976.

D. Electricity

Bonneville Power Administration, Historical Sales Data in Pacific Northwest Area by States, annual summaries 1975-1976, Kalispell, Montana.

Bonneville Power Administration, Historical Sales Data in PNVCC West Group Area by States, annual summaries, 1975-1976, Kalispell, Montana.

Federal Power Commission, Statistics of Privately Owned Electric Utilities in the U.S., Annual Report 1976, Washington, D.C.

Kimball, James A., Analysis of Electrical Load and Supply in Montana for Energy Modeling, prepared for the Montana Energy and MHD Research and Development Institute, Inc., Butte, Montana, 1978.

Kuntz, Gail, Existing Hydroelectric Facilities in Montana, prepared for the Montana Energy and MHD Research and Development Institute, Inc., Butte, Montana, 1978.

Northwest Public Power Association, 1977 Directory, Vancouver, Washington, 1977.

Pacific Northwest Utilities Conference Committee, Long-Range Projection of Power Loads and Resources for Thermal Planning, April 20, 1977.

Pacific Northwest Utilities Conference Committee, Long-Range Projection of Power Loads and Resources for Thermal Planning, April 16, 1976.

Wheeling, Terry, Montana Historical Energy Statistics, Montana Energy Advisory Council, Helenea, Montana, September 1976.

V. ENERGY DEMAND SUBMODEL

The energy demand submodel analyzes the demand for energy in each of the three sectors of the economic activities model: the basic, commercial, and residential sectors. The demand for primary energy sources, coal, oil, electricity, and natural gas, is analyzed for each of the sections and their respective subsectors. Each sector is discussed separately because of the differences in their composition.

A. Methodology

The modeling technique utilized in the formulation of the energy demand submodel is a variant of the traditional activities analysis models associated with operations research methodologies. Operations research methodologies are an accepted means of mathematically representing various types of systems.

The concept of activity as used in the submodel is shown most easily by example. An activity, or the process of producing a good or service, requires inputs to the production process. In addition to the raw material, capital, and labor inputs, the production process also requires energy inputs. These energy inputs, or demands, are the focus of the activity analysis used in the demand model. For example, the production of refined copper requires natural resource, machinery (capital), labor, and extensive amounts of energy--oil for mining equipment, natural gas and electricity for refining, and coal for the process heat used in smelting. This process is functionally notated in the following manner:

$Q = f\ (K,L,X,C,E,G,O)$, where (Eq. V-1)

Q = quantity of output;
f = a functional relationship;
K = capital equipment required;
L = labor used for production;
X = other raw materials required;
C = coal used in production;
E = electricity used in production;
G = natural gas required for production; and
O = oil required for production.

The first term, Q, is generated endogeneously by the energy model in the economic activities submodel. The second term, K, is is assumed to be a constant.* The third term, L, is generated endogeneously by the employment submodel, once the level of output has been established by the economic activities submodel. The fourth term, X, is not within the scope of the modeling effort, and other resources are assumed to be available in sufficient quantities throughout the model's time frame. When these endogeneous and constant terms are removed, equation (1) can be redefined in the following manner:

$$Q = f\ (C,E,G,O) \qquad \text{(Eq. V-2)}$$

This reformulation defines output as a function of energy inputs. For the output of a given level of output x_i, the production process will require a specific amount of each energy source as an input:

$$Qx_i = cx_i + ex_1 + gx_i + ox_i \qquad \text{(Eq. V-3)}$$

The coefficients c,e,g, and o represent the quantity of coal, electricity, natural gas, and oil required for each unit of output produced. These coefficients are computed by dividing the total amount of each energy source used in one year by the total production in that year. The coefficients are computed for each of the sectors and subsectors identified in the economic activities submodel. In addition to the four primary sources of energy, a fifth coefficient which represents the demand for distillate fuels (gasoline, diesel, heating oils, etc.) is computed.

Activities analysis models are predicated on two major assumptions:

- Fixed input ratios; and
- Constant returns to scale.

These assumptions supply require that two units of production need two units of each input. This linear relationship exists over the entire range of production.

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* The productivity parameters allows for changes in labor productivity. This same parameter can be used to simulate changes in capital stocks.

** Activities analysis models assume linear homogeneity of degree one.

B. The Basic Sector

Energy use coefficients for each of the producers in the basic sector are shown in Tables V-1 to V-4. Whenever possible, the annual output is in terms of physical product; when multiple outputs occur or physical output figures are not available, the unit of production utilized is gross dollars of revenue generated.

C. The Commercial Sector

Energy demands in the commercial sector are shown in Tables V-5 to V-7 Growth in the energy demands of the commercial sector are distributed according to the percentage of employment in each of the subsectors. This method is used to maintain consistency with the employment submodel. Because most of the energy demands in the commercial sector are for space heating and cooling, very little distortion in the level of energy demands is expected from this allocation procedure.

D. The Residential Sector

Demands for energy in the residential sector are dependent on the size of the population. The primary use of energy in the residential sector is for housing purposes, Table V-8 . The energy coefficients are computed for a representative household and the total number of households is calculated from the 1970 Census of Population housing occupancy statistics. The data for the residential sector is shown in Table V-9.

E. Price Elasticities, Technology, and Demand

The demand for any product is a function of its price, the price of substitutes, technology, and consumer preferences. When analyzing the demand for specific sources of energy, the importance of these parameters is magnified as the demand is projected into the future.

Activity analysis models do not have a mechanism to compensate for changes in the parameters named above, which determines the demand for one specific fact over another. In order that the Montana Energy Model might be able to simulate changes in these parameters, a deviation from standard activities analysis models is made. The method used by the model to simulate changes in the demand function is to allow the energy demand coefficients to be modified by an exogenously determined elasticity coefficients.

Table V-1

Basic Sector--Coal Demand Coefficients

Sector	Output (000)*	Coal (Tons)	Tons/Output (000)
Agriculture	1,312,572	41	Trace Amount
Mining	26,226,345 (Tons)	2,622	Trace Amount
Contract Construction	331,200	00	00
Durable Goods Manufacturing			
Lumber and Wood Products	441,300	00	Trace Amount
Stone, Clay and Glass	100,300	11,500	.114
Primary Metals			
Copper	180,000 (Tons)	500	.0027
Aluminum	146,177 (Tons)	921	.006
Other	66,572 (Tons)	35,826	1.8
Non-Durable Goods Manufacturing			
Food	343,600	Trace Amount	00
Paper and Pulp	405,565 (Tons)	00	00
Printing & Publishing	38,000	00	00
Petroleum Products	50,322,433	00	00
Other Basic			
Rail	178,700	00	00
Federal Government	N/A		00

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*Whenever possible output is measured in terms of physical output units (short tons), and data is in 1976 dollars when applicable.

Table V-2

Basic Sector--Distillate Oil Demand Coefficients

Sector	Output (000)*	Gallons (000)	Gallons (000)/Output (000)
Agriculture	1,312,572	87,957	.06
Mining	26,226,345 (Tons)	4,589.6	.0001
Contract Construction	331,200	43,978	7.53
Durable Goods Manufacturing			
Lumber and Wood Products	441,300	260,594	.590
Stone, Clay and Glass	100,300	Trace Amount	Trace Amount
Primary Metals Copper	180,000 (Tons)	13,452.6	.074
Aluminum	146,177 (Tons)	8.77	Trace Amount
Other	66,572 (Tons)	124.8	.002
Non-Durable Goods Manufacturing			
Food	343,600	3,948	.011
Paper and Pulp	404,565 (Tons)	191.5	.0004
Printing & Publishing	38,000	00	00
Petroleum Products	50,322,433 (BBL)	39,118	.0008
Other Basic			
Rail	178,700	77,280	.4324
Federal Government	N/A	N/A	.156 (Employee)

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*Whenever possible output is measured in terms of physical output units (short tons), and data is in 1976 dollars when applicable.

Table V-3

Basic Sector--Natural Gas Demand Coefficients

Sector	Output (000)*	MCF/YR	MCF/Output (000)
Agriculture	1,312,572	Trace Amount	Trace Amount
Mining	26,226,345 (Tons)	Trace Amount	Trace Amount
Contract Construction	331,200	Trace Amount	Trace Amount
Durable Goods Manufacturing			
Lumber and Wood Products	441,300	5,600,000	12.68
Stone, Clay and Glass	100,300	4,400,000	43.86
Primary Metals			
Copper	180,000 (Tons)	8,444,200	46.9
Aluminum	146,177 (Tons)	193,245	1.32
Other	66,572 (Tons)	467,932	7.028
Non-Durable Goods Manufacturing			
Food	343,600	2,900,000	8.44
Paper & Pulp	404,565 (Tons)	3,752,135	9.27
Printing & Publishing	38,000	508,000	13.36
Petroleum Products	50,322,433 (BBL)	00	00
Other Basic			
Rail	178,700	00	00
Federal Government	N/A	N/A	32.13 (Employee)

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*Whenever possible output is measured in terms of physical output units (short tons), and data is in 1976 dollars when applicable.

Table V-4

Basic Sector--Electrical Demand Coefficients

Sector	Output (000)*	MWH/YR	MWH/YR/Output (000)
Agriculture	1,312,572	260,000	.198
Mining	26,226,345 (Tons)	131,132	.005
Contract Construction	331,200	300	.001
Durable Goods Manufacturing			
Lumber and Wood Products	441,300	234,213	.53
Stone, Clay and Glass	100,300	101,200	1.008
Primary Metals Copper	180,000 (Tons)	919,032	5.105
Aluminum	146,177 (Tons)	2,293,224	15.68
Other	66,572 (Tons)	37,672	.566
Non-Durable Goods Manufacturing			
Food	343,600	92,800	.27
Paper and Pulp	404,565 (Tons)	152,010	.375
Printing and Publishing	38,000	14,900	.378
Petroleum Products	50,322,433 (BBL)	301,891	.005
Other Basic			
Rail	178,700	23,000	.129
Federal Government	N/A	N/A	6.66 (Employee)

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*Whenever possible output is measured in terms of physical output units (short tons), and data is in 1976 dollars when applicable.

Table V-5

Distillate Oil Demand Coefficients for the Commercial Sector

	Employment	Sq.Ft./Employee	Gallons (000)/Sq.Ft.	Gallons (000)/Employee
ransportation (Except Rail)	6.0	N/A	N/A	.390
ommunications	3.88	177	.0005	.0885
tilities	3.51	247	.0005	.1235
holesale Trade	15.1	209	.0005	.1045
Retail Trade	48.6	175	.0005	.0875
FIRE/S	43.7	390	.0005	.195
ospitals and ursing Homes	14.9	315	.0005	.157
Schools	30.0	700	.0005	.35
Public Administration	22.0	312	.0005	.156

Table V-6

Natural Gas Demand Coefficients for the Commercial Sector

	Employment (000)	Sq. Ft./Employee	MCF/Sq. Ft.	MCF/Employee
Transportation (Except Rail)	6.0	209	.103	21.52
Communications	3.88	177	.103	18.23
Utilities	3.51	247	.103	25.44
Wholesale Trade	15.1	209	.103	21.52
Retail Trade	48.6	175	.103	18.02
FIRE/S	43.7	390	.103	40.17
Hospitals and Nursing Homes	14.9	315	.103	32.445
Schools	30.0	700	.103	72.1
Public Administration	22.0	312	.103	32.13

Table V-7

Electrical Demand Coefficients for the Commercial Sector

	Employment (000)	Sq. Ft./Employee	kWh /Sq. Ft.	MWh /Employee
Transportation (Except Rail)	6.0	209	21.36	4.46
Communications	3.88	177	21.36	3.78
Utilities	3.51	247	21.36	5.27
Wholesale Trade	15.1	209	21.36	4.46
Retail Trade	48.6	175	21.36	3.73
FIRE/S	43.7	390	21.36	8.33
Hospitals and Nursing Homes	14.9	315	21.36	6.73
Schools	30.0	700	21.36	14.9
Public Administration	22.0	312	21.36	6.66

Source: Energy Consumption in Commercial Industries by Census Division, 1974, March 1977, Federal Energy Administration, Washington, D.C.

Table V-8

Residential Energy End Use and Saturation

Use	Electricity W/yr	Natural Gas 10^3 Btu/yr	Oil 10^3 Btu/yr	Coal 10^3 Btu/yr	Bottled Gas & Other 10^3 Btu/yr
Space Heating	27,500 2.3%	118,700 83.8%	141,300 7.1%	161,900 1.9%	118,700 4.9%
Water Heating	4,200 17.9%	20,700 78.7%	26,500 0%	88,300 0%	20,700 2.9%
Kitchen Range	1,180 78.2%	8,130 19.3%			8,130 2.3%
Refrigerator	1,140 105.1%				
Freezer	1,200 65.3%				
Clothes Dryer	990 68.8%	4,110 3.9%			4,110 0.3%
Air Conditioner	460 13.4%				

Table V-9

Average Residential Energy per Household by End Use*

Use	Electricity W	Natural Gas 10^3 Btu	Oil 10^3 Btu	Coal 10^3 Btu	Bottled Gas & Other 10^3 Btu
Space Heating	63	99,500	10,000	3,080	5,820
Water Heating	760	16,300			600
Kitchen Range	920	1,570			190
Refrigerator	1,200				
Freezer	780				
Clothes Dryer	680	160			12
Air Conditioner	62				
Total per Household	5,030	117,500	10,000	3,080	6,620
Toal Montana**	1,170 x 10^6	2,300 x 10^6	2,300 x 10^6	720 x 10^6	1,540 x 10^6

* (Energy per End Use) x saturation

** Assumes 232,500 households

REFERENCES FOR APPENDIX A, SECTION V

The Montana Energy and MHD Research and Development Institute, Montana Natural Gas Demand Study, Butte, Montana, December 1976.

The Montana Energy and MHD Research and Development Institute, Survey Responses to Industrial Uses of Fuel Survey, Butte, Montana, June 1978.

State Department of Labor and Industry, Montana Employment and Labor Force, Research and Analysis Section, Employment Security Division, Helena, Montana, July 1978.

Thompson, Bruce, personal communication, Montana Public Service Commission, Helena, Montana, October 1978.

U.S. Department of Commerce, Annual Survey of Manufacturers, 1976, Bureau of Census, February 1978.

Energy Information Administration, End Use Energy Consumption Data Base, Series I, Tables, U.S. Department of Energy, June 1978.

Energy Information Administration, Federal Energy Data System (FEDS), Statistical Summary, U.S. Department of Energy, February 1978.

National Energy Information Center, Energy Consumption in Commercial Industries by Census Division--1974, U.S. Federal Energy Administration, March 1977.

Office of Energy Conservation and Environment, Physical Characteristics, Energy Consumptions, and Related Institutional Factors in the Commercial Sector, U.S. Federal Energy Administration, February 1977.

VI. DEMOGRAPHIC SUBMODEL

The demographic submodel of the Montana Energy Model has one primary goal: the projection of population levels in any given year. The projection is used to estimate the work force, net migration, and the energy demands of the residential sector.

The model utilizes a cohort-survival technique in order to estimate the number of births, the age distribution of the population, and subsequently, the age distribution of the total population. Cohort-survival models are based on the observation that each age group (cohort) has different survival and fertility rates. Thus, as the age distribution of the population changes, the number of births and deaths will change accordingly. Mathematically, this behavior takes the following form:

$$P_{t+1} = \sum_{i=1}^{N} (C_t^{ij})(S_{t,t+1}^{ij}) + M_{t,t+1}^{ij,i+t,j+1}, \text{ where} \qquad \text{(Eq. V1-1)}$$

P_{t+1} = the population in the time period (t) plus one year;

N = number of cohorts;

C_t^{ij} = the age and sex cohort in time period (t);

S_{t+1}^{ij} = survival note for the age and sex cohort C^{ij}; and

$M_{t,t+1}^{ij,i+1,j+1}$ = any migration for the cohort.

Data for the first independent item (C_t^i) is taken from the decennial census of population. Each cohort is assumed to have a five-year time span. The second independent term (S_t^i) uses data from Current Population Reports, Population Estimates and Projections, Series P-25, No. 601, published by the U.S. Bureau of Census. The last item ($M_{t,t+i}^{ij,i+t,j+1}$) uses data from Montana Population Projections, 1975-2000, published by the Montana Department of Community Affairs.

The demographic submodel has two unique features not usually found with cohort-survival models: 1) an estimate of the work force, and 2) a migration component based on the level of employment. The work force estimation is computed through applying labor force participation rates to each cohort:

$$WF_t = \sum_{i=1}^{N} (C_t^{i,s}) (LFPR)_s^i, \text{ where} \qquad \text{(Eq. VI-2)}$$

WF_t = work force in time period (t);

N = number of cohorts;

$C^{i,s}$ = cohort (i) of sex (s) in time period (t); and

LFPR = labor force participation rate.

The migration componenent computes the net migration on the basis of differences in employment in the state, as opposed to the nation. This method makes the implicit assumption that the labor force will migrate to find work. For example, if state unemployment exceeds national unemployment, there will be a net out-migration. The level of state employment is endogenous to the energy model (in the employment submodel) and the level of national unemployment is set at six percent, the stated policy goal of the current administration.

REFERENCES FOR APPENDIX A, SECTION VI

Montana Department of Community Affairs, Montana Population Projections 1975-2000, Helena, Montana, 1977.

Montana Department of Health and Vital Statistics, 1974 Montana Vital Statistics, Helena, Montana, 1976.

U.S. Bureau of Census, Current Population Reports, Series P. 25, No. 601, U.S. Department of Commerce, Washington, D.C., October 1975.

U.S. Bureau of Census, "Detailed Population Characteristics," 1970 Census of Population, advance report, U.S. Department of Commerce, Washington, D.C., June 1972.

U.S. Bureau of Census, "General Housing Characteristics," 1970 Census of Housing, advance report, U.S. Department of Commerce, Washington, D.C., 1972.

U.S. Bureau of Census, "General Population Characteristics," 1970 Census of Population, U.S. Department ofCommerce, Washington, D.C., August 1971.

U.S. National Center for Health Statistics, Vital Statistics of the United States, U.S. Department of Health, Education, and Welfare, Washington, D.C., 1971.

II. MATHEMATICAL FORMULATION

The submodels of the Montana Energy Model are summarized in this section, and the mathematical equations presented here were used to construct the computer simulation model in Appendix B. The model is designed to be operated in an iterative mode; thus, the calculations made in this model occur in each successive time period. The variable names and definitions written below are the same as those used in the computer code:

. OUTPUT is a vector defining the level of output in basic sector (I);
. GROWTH is an input parameter to simulate growth in the basic sector;
. ENERGY is a matrix of energy use coefficients in the basic sector;
. EMPLOY is a computed vector of employment in the basic sectors;
. OUTEMP is a vector of output/employment ratios in the basic sectors;
. PROD is an input parameter simulating changes in labor productivity;
. COM is a vector of employment shares in the commercial sector;
. OCCUP is an input parameter reflecting occupancy of residences;
. SOURCE is a vector of basic subsector energy demands by energy type;
. ELAST is an input matrix which simulates changes in demand;
. ENER1 is the adjusted matrix--ENER1 = (ENERGY) (ELAST)
. STRAN is the transpose of source;
. ACTUAL is the level of output attainable given the energy type;
. OUTC is the level of output in the commercial subsectors;
. COMD is a vector of commercial demands for energy type (I):
. RUSE is a vector of residential demands for energy type (I);
. RESD is a vector of energy demand coefficients for residences;
. CUSE is a matrix of commercial energy demand coefficients;
. EMP is the level of total employment;
. STOCK is a vector of available energy of type (I):
. TTL is a vector of total energy demands;
. NBS is the number of basic subsectors;
. NCS is the number of commercial subsectors; and
. NT is the number of energy types.

A. Demand Module

The following equations are used in chronological order for the demand module:

1. Calculate desired output levels for each basic sector.

$$\text{OUTPUT}_i = (\text{OUTPUT}_i)\ (\text{GROWTH}_i) \qquad \text{(Eq. VII-1)}$$

2. Adjust energy demand coefficients for price elasticities.

$$\text{ENER1}_{ik} = \sum_{j-1}^{NT} (\text{ENERGY}_{ij})\ (\text{ELAST}_{jk}) \qquad \text{(Eq. VII-2)}$$

$$\text{CUSE}_{nk} = \sum_{j=1}^{NT} (\text{CUSE}_{nj})\ (\text{ELAST}_{jk}) \qquad \text{(Eq. VII-3)}$$

$$\text{RUSE}_j = (\text{RUSE}_j)\ (\text{ELAST}_{jj}) \qquad \text{(Eq. VII-4)}$$

3. Calculate basic employment and productivity changes.

$$\text{BEMP} = \sum_{i=1}^{NBS} (\text{OUTPUT}_i)/(\text{OUTEMP}_i)\ (\text{PROD}_i) \qquad \text{(Eq. VII-5)}$$

4. Calculate commercial sector employment.

$$\text{COMEMP} = 3.737\ (\text{BEMP})\text{--estimate is in Section II} \qquad \text{(Eq. VII-6)}$$

5. Allocate commercial sector employment among the subsectors.

$\text{OUTC}_i = (\text{COMEMP})\ (\text{COM}_i)$, where

$i = 1 \ldots \text{NCS}$ (Eq. VII-7)

6. Calculate the number of residences.

$$\text{RESI} = \text{POP}/\text{OCCUP} \qquad \text{(Eq. VII-8)}$$

7. Calculate basic sector energy demands.

$\text{SOURCE}_j = \sum_{i=1}^{NBS} (\text{OUTPUT}_i)\ (\text{ENERI}_{ji}) + \text{SOURCE}_j$, where

$j = 1 \ldots \text{NT}$, and

$i = 1 \ldots \text{NBS}$ (Eq. VII-9)

8. Calculate commercial sector energy demands.

$$\text{COMP}_j = \sum_{i=1}^{NCS} (\text{OUTC}_i)\ (\text{CUSE}_{ji}) + \text{OUTC}_i \qquad \text{(Eq. VII-10)}$$

9. Calculate residential sector energy demands.

$\text{RESD}_j = (\text{RESI})\ (\text{RUSE}_j)$, where

$j = 1 \ldots \text{NT}$ (Eq. VII-11)

10. Calculate total energy demand.

$TTL_j = SOURCE_j + COMP_j + RESD_j$, where

$j = 1 \ldots NT$ (Eq. VII-12)

B. Supply Module

The following equations are used in chronological order for the supply module:

1. Calculate coal supplies (supply equals demand).

$STOCK\ (1) = TTL\ (1)$ (Eq. VII-13)

2. Calculate oil supplies.

CRUDE = Discovered + Wyoming + Canada (Eq. VII-14)

$STOCK_2 = CRUDE$ (Eq. VII-15)

3. Calculate the least cost source of gas (supply equals demand).

$STOCK_3 = TTL_3$ (Eq. VII-16)

Minimize $z = \Sigma\, c_i\, p_i\, x_i$, where (Eq. VII-17)

$i = 1 \ldots n$,

c = cost of $source_i$;

p = risk of $source_i$;

x = amount of $source_i$; subject to

$\Sigma\, a_{ij} x_i \geq r_i$; where

$i = 1 \ldots n$;

$j = 1 \ldots m$; and

$x_i \geq 0$.

4. Calculate the least cost source of electricity (supply equals demand).

$STOCK_4 = TTL_4$ (Eq. VII-18)

Minimize $\sum_{j=1}^{r} c_j x_j$, subject to

$\sum_j \frac{1}{e_{ij}}\, x_j \leq S_u$, where (Eq. VII-19)

$u = 1 \ldots n_j$;

x_j = type of producer;

c_j = cost per MWH for producer j; and

e_{ij} = facility load factor

$\Sigma_j \; d_{vj} x_j = D_v$, where (Eq. VII-20)

$v = 1 \ldots m$;

$x_j \geq 0$; and

d_{vj} = sum of the demands

5. Calculate the supply of distillate fuels.

$STOCK_5 = (0.5)\,(STOCK_2)$ (Eq. VII-21)

6. Reconcile supply and demand and set output levels subject to energy available.

$TTL_j = STOCK_j$ (Eq. VII-22)

$TTL_j = TTL_j - RESD_j - COMP_j$ (Eq. VII-23)

7. Calculate actual output possible.

$Actual_i = \Sigma(TTL_j)\,(ENER1_{ji}) + ACTUAL_i$, where (Eq. VII-24)

$i = 1 \ldots NBS$; and

$j = 1 \ldots NT$

8. Return to equation VII-1 and retry; if supply $_j$ equals demand $_j$, then continue.

C. Demographic Module

The following equations are used in chronological order for the demographic module.

1. Calculate total population levels.

$P_{t+1} = \mathop{E}_{i=1}^{N} (C_t^{ij})\,(S^{ij}_{t,t+1}) + M^{ij,i+t,j+1}_{t,t+1}$, where (Eq. VII-25)

P_{t+1} = the population in the time period (t) plus one year;

N = number of cohorts;

C^{ij}_t = the age and sex cohort in time period (t);

S^{ij}_{t+1} = survival note for the age and sex cohort C^{ij}; and

$M^{ij,\, i+1,\, j+1}_{t,t+1}$ = any migration for the cohort.

2. Calculate the labor force.

$WF_t = \sum_{i=1}^{N} (C_t^{i,s}) (LFPR)^{i,s}$, where (Eq. VII-26)

WF_t = work force in time period (t);

N = number of cohorts;

$C^{i,s}$ = cohort (i) of sex(s) in time period (t); and

$LFPR^{i,s}$ = labor force participation rate of cohort (i) and sex (s).

3. Calculate the level of unemployment.

UNEMP = (EMP-WF)/WF (Eq. VII-27)

4. Compare state unemployment to the national unemployment and calculate migration.

$MIG = (NATEMP - UNEMP)\ (M_{t,t+1}^{ij,i+1,j+1})$ where (Eq. VII-28)
NATEMP = National Unemployment, 0.06
ij = an age sex cohort;

t = time period, t;

t+1 = time period t+1 year; and

M = migration rates for the ij^{th} cohort.

D. Shadow Prices and Slack Variables

The output generated in the electrical and natural gas supply models includes the shadow prices held by the slack variables used to create equalities from the constraint equations. Shadow pricing can be interpreted as an opportunity cost associated with a given variable (e.g., the peaking constraints in the electrical model have a negative shadow price, indicating that constraining these devices to a low load factor causes a higher cost for the average unit of electricity). Slack variables are indicative of excess capacity within the system; an example of a slack variable is constraining the size of thermal power plants to large blocks of power, thereby creating excess productive capacity in the short run.

APPENDIX B

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APPENDIX B

Appendix B consists of the computer source code, input data, and a sample output of the Montana Energy Model. The computer source code is the listing of the computer simulation model utilized in the Montana Energy Model. The source code is written to be compiled using a Data General Corporation FORTRAN IV compiler in conjunction with an Eclipse AOS operating system.

The subroutines are listed in the order in which the program calls them. Variable definitions for all relevant variables are listed at the head of the calling routine. The comment statements in the program should make the subroutines easier to follows.

```
C            ********* MONTANA ENERGY MODEL *********
C      THE PROGRAM ENERGY IS THE DRIVER FOR THE ENERGY MODEL
C      *****************************************************
C      SET UP THE COMMON FOR THE MAIN PROGRAM
C      ****************************************************
       COMMON/CMAIN/IDATE,IWRIR
       DIMENSION OUTPUT(15),GROWTH(15),ENERGY(15,5)
      1,EMPLOY(15),OUTEMP(15),PROD(15),COM(15),SOURCE(5)
      2,ELAST(5,5),ENER1(15,5),STRAN(5),ACTUAL(15),OUTC(15)
      3,COMD(5),RESD(5),ROSE(5),COSE(15,5),STOCK(5)
      4,HOLD(15),PERCENT(15,5),TIL(5)
C         ************************************************
C         VARIABLE DEFINITIONS
C         ************************************************
C         OUTPUT IS A VECTOR DEFINING THE LEVEL OF OUTPUT IN
C         BASIC SECTOR(I)
C         GROWTH IS AN INPUT PARAMETER TO STIMULATE GROWTH IN
C         THE BASIC SECTOR
C         ENERGY IS A MATRIX OF ENERGY USE COEFFICIENTS IN THE
C         BASIC SECTOR
C         EMPLOY IS A COMPUTED VECTOR OF EMPLOYMENT IN THE
C         BASIC SECTORS
C         OUTEMP IS A VECTOR OF OUTPUT/EMPLOYMENT RATIOS IN
C         THE BASIC SECTOR
C         PROD IS AN INPUT PARAMETER SIMULATING CHANGES IN
C         LABOR PRODUCTIVITY
C         COM IS A VECTOR OF EMPLOYMENT SHARES IN THE COM-
C         MERCIAL SECTOR
C         OCCUP IS AN INPUT PARAMETER REFLECTING OCCUPANCY OF
C         RESIDENCES
C         SOURCE IS A VECTOR OF ENERGY DEMANDS BY ENERGY TYPE
C         ELAST IS AN INPUT MATRIX WHICH SIMULATES CHANGES IN
C         DEMAND
C         ENER1 IS THE ADJUSTED ENERGY MATRIX-
C                 ENER1=ENERGY*ELAST
C         STRAN IS THE TRANSPOSE OF SOURCE
C         ACTUAL IS THE LEVEL OF OUTPUT ATTAINABLE GIVEN THE
C         ENERGY TYPE
C         OUTC IS THE LEVEL OF OUTPUT IN THE COMMERCIAL
C         SUBSECTORS
C         COMD IS A VECTOR OF COMMERCIAL DEMANDS FOR ENERGY
C         TYPE(I)
C         ROSE IS A VECTOR OF RESIDENTIAL DEMANDS FOR ENERGY
C         TYPE(I)
C         RESD IS A VECTOR OF ENERGY DEMAND COEFFICIENTS FOR
C         RESIDENCE
C         COSE IS A MATRIX OF COMMERCIAL ENERGY DEMAND
C         COEFFICIENTS
C         EMP IS THE LEVEL OF TOTAL EMPLOYMENT
C         STOCK IS A VECTOR OF AVAILABLE ENERGY OF TYPE (I)
C         HOLD IS A DUMMY VARIABLE
C      **********************************************
C      SET UP THE COMMON FOR THE OIL SUBROUTINE
```

```
C       ***********************************************
        COMMON /OIL/XFNC(5,10,2),IFNC(5,5),IERROR,NW,S1,S2,S3
       1S4,S5,A1,A2,A3,A4,A5,F1,F2,F3,F4,E1,D1,D2,D3,D4,IY
       2,WYOMING,CANADA,RWYO,RCAN
C          *******************************************
C          COMMON FOR DEMOGRAPHIC SUBROUTINE
C          *******************************************
           COMMON/COHORT/AF(17),AM(17),B(8),OF(17),DM(17)
       1,DF(17),OM(17),BR,ALPHA,IP,IM,IF,IB,NB,IB
       2,LFPRM(17),LFPRF(17),SAT,WORK,EMP,UNEMP
C         *********************************************
C          DIMENSION FOR ELECTRICAL SUPPLY SUBMODEL
C          ********************************************
           DIMENSION AA(10,20),BB(10),ZZT(20),KODER(20),CCJ(20)
       1,ZHOLD(10)
           DIMENSION AHOLD(10,20),AAA(10,20)
C          ********************************************
C          DIMENSION FOR GAS SUBROUTINE
C          ********************************************
           DIMENSION A(10,20),BC(20),ZC(20),KODSEN(20)
       1,CJ(20),HOLDS(25,6)
C          *******************************************
C        INITIALIZE DATA FILES
C        ********************************************
         CALL OPEN (12,"@LPT",2,IER)
         CALL OPEN (20,'OILMOD1',2,IER)
         CALL OPEN (26,"DDAT",2,IER)
         CALL OPEN (27,"LABOR",2,IER)
         CALL OPEN(28,'ELECT.DAT',2,IER)
         CALL OPEN(29,'DATA.MOD',2,IER)
         CALL OPEN(30,'PARAM',2,IER)
         CALL OPEN(31,'GAS.DAT',2,IER)
C        ***************************************************
C        INITIALIZE DATA TO ZERO
C        ***************************************************
         DO 1 I=1,15
         OUTPUT(I)=0.0
         GROWTH(I)=0.0
         EMPLOY(I)=0.0
         OUTEMP(I)=0.0
         PROD(I)=0.0
         COM(I)=0.0
         ACTUAL(I)=0.0
         OUTC(I)=0.0
         HOLD(I)=0.0
1        CONTINUE
         DO 2 I=1,5
         STRAN(I)=0.0
         ROSE(I)=0.0
         STOCK(I)=0.0
         RESO(I)=0.0
         COMD(I)=0.0
2        CONTINUE
```

```
      DO 5 I=1,15
      DO 5 J=1,5
      PERCENT(I,J)=0.0
      ENERGY(I,J)=0.0
      ENER1(I,J)=0.0
      COSE(I,J)=0.0
5     CONTINUE
C     ***************************************************
C     READ IN DATA FOR DRIVER
C     ***************************************************
      READ(29,250)NBS,NV,NT,NCS,IDATE,INCMT
      DO 251 I=1,NBS
      READ(29,252)(ENERGY(I,J),J=1,NT),OUTPUT(I),OUTEMP(I)
      READ(30,253)GROWTH(I),PROD(I)
251   CONTINUE
      DO 254 I=1,NCS
      READ(29,255)(COSE(I,J),J=1,NT),COM(I)
254   CONTINUE
      READ(29,259)(ROSE(I),I=1,NT)
      DO 256 I=1,NT
      READ(29,257)(FLAST(I,J),J=1,NT)
256   CONTINUE
250   FORMAT(I2,1X,2(I1,1X),I2,1X,I4,1X,I2)
252   FORMAT(2(F5.4,1X),F5.3,1X,F5.3,1X,F5.4,1X,F8.0,1X,
     1F8.2)
253   FORMAT(F5.4,1X,F5.4)
255   FORMAT(4(F5.2,1X),F5.4,1X,F5.3)
257   FORMAT(4(F5.4,1X),F5.4)
259   FORMAT(F5.3,1X,F5.4,1X,F5.2,1X,F5.4,1X,F5.4)
C     ********************************************
C     READ INPUTS FOR OIL SUPPLY SUBROUTINE
C     ********************************************
C     FUNCTIONS
      READ(30,258)WYOMING,CANADA,RWYO,RCAN
258   FORMAT(F6.0,1X,F6.0,1X,2(F4.3,1X))
      DO 100 I=1,5
      READ(20,1000) (IFNC(I,J),J=1,5)
      NV=IFNC(I,4)
  100 READ(20,1001) ((XFNC(I,J,K),K=1,2),J=1,NV)
C     STATE VARIABLES
      READ(20,1001) S1,S2,S3,S4,S5
      NN=12
 1000 FORMAT(8I10)
 1001 FORMAT(5F15.5)
C       *****************************************
C       DATA INPUT FOR DEMOGRAPHIC SUBROUTINE
C       ******************************************
        DO 171 I=1,16
        READ (27,103)FPRM(I),FPRF(I)
        READ(26,101)DF(I),DM(I),AF(I),AM(I),OM(I),OF(I)
 171    CONTINUE
        READ(26,104)NB,IR,SAT,BR,IP,OFLOP
        READ(26,102)(B(I), I=1,NB)
```

```
      READ(26,105)EMP
      READ(26,106)XXXX
      READ(26,105)YYYY
 101  FORMAT(F3.3,1X,F3.3,1X,F5.0,1X,F5.0,1X,F3.3,1X,F3.3)
 102  FORMAT(F4.4)
 103  FORMAT(I3,1X,I3)
 104  FORMAT(2(I1,1X),F3.3,1X,F4.3,1X,F6.0,1X,F3.2)
 105  FORMAT(F6.0)
 106  FORMAT(F4.3)
C     ***********************************************
C     DATA FOR ELECTRICAL SUPPLY MODEL
C     ***********************************************
      GEN=883.0
      FLOW=8760.0
      READ(28,1203)ICOL,IROW,NZER,ICOD
      DO 172 NXI=1,IROW
      READ(28,1201)(AA(NXI,NXJ), NXJ=1,ICOL),FODER(NXI),
     1ZHOLD(NXI)
 172  CONTINUE
      READ(28,1202)(CCJ(I),I=1,ICOL)
1201  FORMAT(4(F2.1,1X),I1,1X,F3.2)
1202  FORMAT(F3.0)
1203  FORMAT(3(I1,1X),I1)
C     *****************************************
C     DATA INPUTS FOR THE GAS SUBMODEL
C     *****************************************
      READ(31,181)IC,IR,NNNC,KODE
      READ(31,184)(CJ(I),I=1,IC)
      DO 1800 I=1,IR
      READ(31,182)(A(I,J),J=1,IC),KODSEN(I)
1800  CONTINUE
      DO 1801 I=1,50
      READ(31,183,END=181)(HOLDS(I,J),J=1,IR)
1801  CONTINUE
 181  FORMAT(5(I2,1X))
 182  FORMAT(5(F4.3,1X),I1)
 183  FORMAT(5(F4.1,1X),F4.1)
 184  FORMAT(4(F4.3,1X),F4.3)
C     ****************************************
C     COMPUTE THE DESIRED OUTPUT LEVEL
      DO 1919 INCRE=1,INCMT
C     COMPUTE OUTPUT LEVELS FOR THE ENERGY MODEL
C     ADJUST DEMAND COEFFICIENTS FOR ELASTICITIES
      DO 13 I=1,NBS
      DO 13 J=1,NT
      ENER1(I,J)=0.0
      DO 13 K=1,NT
      ENER1(I,J)=ENER1(I,J)+ENERGY(I,K)*ELAST(K,J)
  13  CONTINUE
      DO 19 I=1,NCS
      DO 19 J=1,NT
      COSE(I,J)=0.0
      DO 19 K=1,NT
```

```
          COSE(I,J)=COSE(I,J)+ENERGY(I,K)*ELAST(K,J)
   19     CONTINUE
          DO 21 I=1,NT
          ROSE(I)=ROSE(I)*ELAST(I,I)
   21     CONTINUE
          DO 14 I=1,NBS
          DO 14 J=1,NT
          KT=0
          DO 15 K=1,NBS
          KT=KT+ENERGY(K,J)
   15     CONTINUE
          PERCENT(I,J)=ENERGY(I,J)/KT
   14     CONTINUE
          DO 201 I=1,NBS
          OUTPUT(I)=OUTPUT(I)*GROWTH(I)
  201     CONTINUE
C         COMPUTE THE NUMBER OF RESIDENTIAL USERS
          RESI=TP/OCCUP
C         COMPUTE BASIC SECTOR EMPLOYMENT
 1111     BEMP=0.0
          COSE(2,1)=GEN*YYYY
          DO 31 I=1,NT
          SOURCE(I)=0.0
          COMD(I)=0.0
   31     CONTINUE
          DO 202 I=1,NBS
          EMPLOY(I)=OUTPUT(I)/(OUTEMP(I)*PROD(I))
          BEMP=BEMP+EMPLOY(I)
  202     CONTINUE
          DO 1003 I=1,6
          DO 1003 J=1,6
          AHOLD(I,J)=A(I,J)
          AAA(I,J)=AA(I,J)
 1003     CONTINUE
C         COMPUTE COMMMERCIAL SECTOR EMPLOYMENT
          COMEMP=BEMP*XXXX
          EMP=COMEMP+BEMP
C         ALLOCATE COMMERCIAL SECTOR EMPLOYMENT BY SUBSECTOR
          DO 203 I=1,NCS
          OUTC(I)=COMEMP*COM(I)
  203     CONTINUE
C         *********************************************
C         COMPUTE ENERGY DEMAND LEVELS FOR EACH SECTOR AND
C         *********************************************
C         TOTAL
C         *********************************************
          DO 10 I=1,NBS
          DO 10 J=1,NT
          SOURCE(J)=OUTPUT(I)*ENER1(I,J)+SOURCE(J)
   10     CONTINUE
C         COMMERCIAL SECTOR
          DO 11 I=1,NCS
          DO 11 J=1,NT
```

```
          COMD(J)=OUTC(I)*COSE(I,J)+COMD(J)
   11     CONTINUE
C         RESIDENTIAL SECTOR
          DO 207 I=1,NI
          RESD(I)=REST*RUSE(I)
207       CONTINUE
C         TOTAL DEMAND
          DO 208 I=1,NI
          TTL(I)=SOURCE(I)+RESD(I)+COMD(I)
208       CONTINUE
          IF(IWRTR.EQ.0)GO TO 209
         CALL WRTR (OUTPUT,GROWTH,ENERGY
        1,EMPLOY,OUTEMP,PROD,COM,OCCUP,SOURCE
        2,ELAST,ENERT,STRAN,ACTUAL,OUTC
        3,COMD,RESD,RUSE,COSE,STOCK
        4,HOLD,PERCENT,NBS,NV,NI,NCS)
C         CHECK AVAILABLE SUPPLIES
209       CALL OILSUP(STOCK(2),INCRE)
          CALL GAS(TTL(3),STOCK(3),INCRE,AHOLD,
        1BC,ZC,KODSEM,JC,IR,KODE,CJ,OBJ,NNNC,HOLDS)
          CALL ELECT (TTL(4),STOCK(4),AAA,BB,ZZT,KODER,CCJ
        1,ICOL,IROW,NZER,ICOD,GEN,ZHOLD,FLOW)
          STOCK(1)=TTL(1)
C         ADJUST DISTILLATE OIL FIGURE TO MGAL
          STOCK(5)=.5*STOCK(2)/23.8
          DO 205 I=1,NI
          SOURCE(I)=TTL(I)
          IF(SOURCE(I).LE.STOCK(I))GO TO 205
          SOURCE(I)=STOCK(I)
205       CONTINUE
          IF (IWRTR.GT.0)GO TO 212
C         SET IWRTR TO PRINT MODE
          IWRTR=1
C         COMPUTE THE LEVEL OF OUTPUT POSSIBLE
          DO 211 I=1,NI
          SOURCE(I)=SOURCE(I)-COMD(I)-RESD(I)
211       CONTINUE
          DO 12 I=1,NBS
          DO 12 J=1,NI
          ACTUAL(I)=PERCENT(I,J)*SOURCE(J)+ACTUAL(I)
          ACTUAL(I)=OUTPUT(I)
   12     CONTINUE
          DO 213 I=1,NBS
          HOLD(I)=OUTPUT(I)
          OUTPUT(I)=ACTUAL(I)
213       CONTINUE
          OUTPUT(12)=STOCK(2)
          IF(STOCK(2).EQ.0)OUTPUT(12)=TTL(2)
          GO TO 1111
212       CONTINUE
          CALL DEMOG(EMP)
C         RESET IWRTR TO PASSIVE MODE
          IWRTR=0
```

```
      IDATE=IDATE+1
1919  CONTINUE
      END
```

```
       SUBROUTINE WRIR (OUTPUT,GROWTH,ENERGY
      1,EMPLOY,OUTEMP,PROD,COM,OCCUP,SOURCE
      2,ELAST,ENER1,STRAN,ACTUAL,OUTC
      3,COMD,RESD,RUSE,CUSE,STOCK
      4,HOLD,PERCENT,NBS,NV,NT,NCS)
C         SUBROUTINE WRIR PRINTS THE OUTPUT FROM THE ENERGY MODEL
       COMMON/CMAIN/IDATE,IWRIR
       DIMENSION OUTPUT(NBS),GROWTH(NBS),ENERGY(NBS,NT)
      1,EMPLOY(NBS),OUTEMP(NBS),PROD(NBS),COM(NBS),SOURCE(NT)
      2,ELAST(NT,NT),ENER1(NBS,NT),STRAN(NT),ACTUAL(NBS),OUTC(NBS)
      3,COMD(NT),RESD(NT),RUSE(NT),CUSE(NBS,NT),STOCK(NT)
      4,HOLD(NBS),PERCENT(NBS,NT)
          DIMENSION SHORT(15),TOTAL(15)
          DO 100 I=1,NBS
          SHORT(I)=HOLD(I)-ACTUAL(I)
          IF(SHORT(I).LT.0)GO TO 100
          SHORT(I)=0.0
100       CONTINUE
          DO 200 I=1,NT
          TOTAL(I)=SOURCE(I)+RESD(I)+COMD(I)
200       CONTINUE
C         PRINT OUTPUT
          WRITE(12,1000)IDATE
          WRITE(12,1001)
          WRITE(12,1002)
          DO 2 I=1,14
 2        WRITE(12,1003)I,HOLD(I),ACTUAL(I),SHORT(I)
          WRITE(12,1004)
          WRITE(12,1005)
          WRITE(12,1006)
          WRITE(12,1007)
          WRITE(12,1008)(TOTAL(I),I=1,NT)
          WRITE(12,1009)
          WRITE(12,1007)
          WRITE(12,1008)(SOURCE(I),I=1,NT)
          WRITE(12,1010)
          WRITE(12,1007)
          WRITE(12,1008)(COMD(I),I=1,NT)
          WRITE(12,1011)
          WRITE(12,1007)
          WRITE(12,1008)(RESD(I),I=1,NT)
1000      FORMAT(1H1,////,20(1H*),5X,I5,5X,20(1H*),/////)
1001      FORMAT(10X,'PRODUCTION LEVELS IN THE BASIC SECTOR',//)
1002      FORMAT(10X,'SECTOR',7X,'DESIRED OUTPUT',7X,'ACTUAL
      1OUTPUT',8X,'SHORTFALL',//)
1003      FORMAT(/,12X,I5,5X,3(F15.5,5X))
1004      FORMAT(1H1,/////)
1005      FORMAT(20X,20(1H*),5X,'ENERGY DEMANDS',5X,20(1H*),///)
1006      FORMAT(20X,20(1H*),5X,'TOTAL DEMAND',5X,20(1H*),//)
1007      FORMAT(15X,'COAL',15X,'OIL',15X,'GAS',15X,'ELECT',15X,
      1'DIST',//)
1008      FORMAT(8X,5(F15.5,5X),//)
1009      FORMAT(20X,20(1H*),5X,'BASIC SECTOR',5X,20(1H*),//)
```

```
1010     FORMAT(20X,20(1H*),5X,'COMMERCIAL SECTOR',5X,20(1H*),//)
1011     FORMAT(20X,20(1H*),5X,'RESIDENTIAL SECTOR',5X,20(1H*),//)
         RETURN
         END
```

```
      SUBROUTINE OILSUP(CRUDE,INCRE)
      COMMON /CMAIN/IDATE,IWRTR
      COMMON /OIL/XFNC(5,10,2),IFNC(5,5),IERROR,NW,S1,S2,S3,S4,
     1S5, A1,A2,A3,A4,A5,F1,F2,F3,F4,E1,D1,D2,D3,D4,IY,WYOMING
     2,CANADA,RWYO,RCAN
      COMMON/ /IS
C       ***************************************************
C       *********** STATE VARIABLES ***********************
C       S1=SMOOTHED PRODUCTIVITY (BBL/$ SPENT)
C       S2=SMOOTHED DISCOVERY MULTIPLIER
C       S3=NORMAL DRILLING RATE
C       S4=UNDISCOVERED OIL(BBL)
C       S5=CUMMULATIVE DISCOVERED OIL(BBLS)
C       ******** DERIVATIVES *****************
C       D1=SMOOTHED PRODUCTIVITY
C       D2=SMOOTHED DISCOVERY MULTIPLIER
C       D3=NORMAL DRILLING RATE
C       D4=DISCOVERY RATE (BBL/YEAR)
C       ************ ANCILLARY VARIABLES **************************
C       A1=RETURN RATIO ($/BBL)/(BBL/$ SPENT)
C       A2=DRILLING RATE ($/YEAR)
C       A3=NORMAL DISCOVERY (BBL/YR)
C       A4=ACTUAL PRODUCTIVITY(BBL DISCOVERED/$)
C       A5=DISCOVERY RATIO
C       *************** EXOGENOUS VARIABLES ***************
C       E1=WELLHEAD PRICE (1976 DOLLARS/BBL)
C       ************ FUNCTIONS *******************
C       F1=EXPLORATORY DRILLING  $/YEAR VS. RETURN RATIO
C       F2=BBL DISCOVERED/$ SPENT VS. CUMMULATIVE DISCOVERY
C       F3=DRILLING RATE ADJUSTMENT VS. DISCOVERY MULTIPLIER
C       F4=SIZE OF A MAJOR DISCOVERY (BBL/YEAR)
C       ****************************************************
      IY=IDATE
      CALL OSTAT
      IF(IWRTR.EQ.0) GO TO 2222
C     OUTPUT RESULTS
      WRITE(NW,1004) IDATE
      CANADA=CANADA*RCAN
      WYOMING=WYOMING*RWYO
      CRUDE=(S3*A1*.3)+WYOMING+CANADA
      WRITE(12,1255)
      WRITE(NW,1005) S1,S2,S3,S4,S5
      WRITE(12,1212)
      WRITE(NW,1006) A1,A2,A3,A4,A5
      WRITE(12,1214)
      WRITE(NW,1007) F1,F2,F3,F4
      WRITE(12,1213)
      WRITE(NW,1008) E1
      WRITE(12,1111)
      WRITE(12,1009)CRUDE
      CALL OUPDAT
 1004 FORMAT(1H1,///11X,20(1H*),2X,I5,2X,20(1H*),///)
 1255 FORMAT(2X,'********** STATE VARIABLES *************',//)
```

```
1005  FORMAT(1X,'SMOOTHED PRODUCTIVITY (BBL/$ SPENT)     ',F15.5//
    1           1X'SMOOTHED DISCOVERY MULTIPLIER            ',F15.5//
    1          1X,'NORMAL DRILLING RATE                     ',F15.5//
    1          1X,'UNDISCOVERED OIL(BBL)                    ',F15.5//
    1             1X,'COMMULATIVE DISCOVERED OIL(BBLS)
    1             ',F15.5,////)
1212   FORMAT(2X,'************ ANCILLARY VARIABLES *************',//)
1006   FORMAT(1X,'RETURN RATIO (S/BBL)/(BBL/$ SPENT)     ',F15.5,//
    1     1X,'DRILLING RATE ($/YEAR)                      ',F15.5,//
    1     1X,'NORMAL DISCOVERY (BBL/YR)                   ',F15.5,//
    1     1X,'ACTUAL PRODUCTIVITY(BBL DISCOVERED/$)       ',F15.5,//
    1     1X,'DISCOVERY RATIO
    1     ',F15.5,////)
1213   FORMAT(2X,'*************** EXOGENOUS VARIABLES **********
    1 *****',//)
1008   FORMAT(1X,'WELLHEAD PRICE (1976 DOLLARS/BBL)     ',F15.5,//)
1214   FORMAT(2X,'************ FUNCTIONS *******************',//)
1007   FORMAT(1X,'EXPLORATORY DRILLING  $/YEAR VS. RETURN RATIO
    1 ',F15.5,//
    1         1X,'BBL DISCOVERED/$ SPENT VS. COMMULATIVE DISCOVERY
    1         ',F15.5//
    1         1X,'DRILLING RATE ADJUSTMENT VS. DISCOVERY MULTIPLIER
    1         ',F15.5//
    1         1X,'SIZE OF A MAJOR DISCOVERY (BBL/YEAR)
    1         ',F15.5///)
1111  FORMAT(/,2X,'**************  OTHER  *****************',//)
1009  FORMAT(1X,'CRUDE AVAILABLE FOR MONTANA REFINERS',5X,E15.5)
2222  RETURN
      END
```

```
      SUBROUTINE OSTAT
      COMMON /OIL/XFNC(5,10,2),IFNC(5,5),IERROR,NW,S1,S2,
     1S3,S4,S5,A1,A2,A3,A4,A5,F1,F2,F3,F4,E1,D1,D2,D3,D4,IY,
     2WYOMING,CANADA,RWYO,RCAN
      AIY=IY
      CALL OAFNC(AIY,E1,5)
      A1=E1/S1
      CALL OAFNC(A1,F1,1)
      CALL OAFNC(S2,F3,3)
      A2=F3*S3
      CALL OAFNC(S5,F2,2)
      A3=A2*F2
      CALL OAFNC(AIY,F4,4)
      D4=A3*F4
      A4=D4/A2
      A5=D4/A3
      D1=((1./A4)-S1)/5.
      D2=(A5-S2)/2.
      D3=(F1-S3)/3.
      RETURN
      END
```

```
      SUBROUTINE DAFNC(XZ,Y,IZ)
      COMMON /OIL/XFNC(5,10,2),IFNC(5,5),IERROR,NW,S1,S2,S3,
     1S4,S5,A1,A2,A3,A4,A5,F1,F2,F3,F4,E1,D1,D2,D3,D4,IY,
     2WYOMING,CANADA,RWYO,RCAN
C  ***************************************************************
C  REASSIGN THE INPUT ARGUEMENTS
      X=XZ
      I=IZ
C  THIS IS A SUBROUTINE WHICH INTERPOLATES BETWEEN TABLED
C  FUNCTION
C  VALUES BY FITTING A POLYNOMIAL TO A NUMBER OF POINTS
C  X IS THE VALUE OF THE INDEPENDENT VARIABLE
C  Y IS THE VALUE OF THE DEPENDENT VARIABLE CALCULATED
C  I IS THE FUNCTION NUMBER
C  TWO ARRAYS MUST BE SUPPLIED TO IT THROUGH COMMON
C  THE USER MUST SUPPLY A COMMON STATEMENT SUITABLE FOR THE
C  FUNCTIONS
C  BEING USED
C  XFNC(I,J,K) IS THE ARRAY WHICH CONTAINS THE TABLED FUNCTION
C  I IS THE NUMBER OF THE FUNCTION BEING USED
C  J IS THE INDEX FOR FUNCTION POINTS
C  K IS 1 FOR THE INDEPENDENT VARIABLE AND 2 FOR THE DEPENDENT
C  VARIABLE
C  IFNC(I,J) DESCRIBES THE NATURE OF THE FUNCTION
C  I IS THE NUMBER OF THE FUNCTION
C  THE J VALUES ARE USED TO CONVEY INFORMATION ABOUT THE
C  FUNCTION
C  1 STANDS FOR YES, 0 STANDS FOR NO
C  J=1--EXTEND FUNCTION BELOW MINUMUM VALUE OF INDEPENDENT
C  VARIABLE
C  J=2--EXTEND  FUNCTION BEYOND MAXIMUM VALUE OF INDEPENDENT
C  VARIABLE
C  J=3--EQUALLY SPACED VALUES OF INDEPENDENT VARIABLE
C  J=4--IS USED FOR THE NUMBER OF DATA POINTS IN THE FUNCTION
C  J=5--IS USED FOR THE NUMBER OF DATA POINTS TO BE USED
C  IN THE INTERPOLATION
C  IERROR IS A SIGNAL USED TO INDICATE A MALFUNCTION IN THE
C  INTERPOLATION
C  0 INDICATES NO ERRORS.  1 INDICATES AN ERROR
C      NW IS THE PRINTER NUMBER FOR ERROR MESSAGES
C
C
C  REASSIGN OFTEN USED ARRAY VALUES
      J4=IFNC(I,4)
      J5=IFNC(I,5)
      X1=XFNC(I,1,1)
      XN=XFNC(I,J4,1)
C  INITIALIZE ERROR PARAMETER
      IERROR=0
C  CHECK TO SEE IF X IS IN THE PROPER RANGE
      IF(X.GE.X1) GO TO 103
      IF(IFNC(I,1).EQ.1) GO TO 102
      WRITE(NW,1011) I,X
```

```
  101 FORMAT(24H BELOW RANGE OF FUNCTION,I4,G15.4)
      IERROR=1
  102 Y=XFNC(I,1,2)
      RETURN
  103 IF(X.LE.XN) GO TO 106
      IF(IFNC(I,2).EQ.1) GO TO 105
      WRITE(NW,104) I,X
  104 FORMAT(24H ABOVE RANGE OF FUNCTION,I4,G15.4)
      IERROR=1
  105 Y=XFNC(I,J4,2)
      RETURN
C  FIND STARTING POINT FOR SEARCH FOR INDEPENDENT VARIABLE INDEXES
  106 IX=IFIX(((X-X1)/(XN-X1))*FLOAT(J4-1))+1
      IF(IX.EQ.J4) IX=J4-1
C  ARE VALUES OF INDEPENDENT VARIABLE EQUALLY SPACED
      IF(IFNC(I,3).EQ.0) GO TO 110
C ARE AN EVEN OR ODD NUMBER OF DATA POINTS TO TO BE USED
 1065 A=FLOAT(J5)*.5
      IA=IFIX(A+.1)
      IF(A.GT.FLOAT(IA)) GO TO 107
      IX=IX-IA+1
      GO TO 150
C  WHICH PART OF INTERVAL IS POINT IN
  107 J=0
      X11=XFNC(I,IX+1,1)
      IF((X11-X)/(X11-XFNC(I,IX,1)).LT.0.5) J=1
      IX=IX-IA+J
      GO TO 150
C  SEARCH FOR INDEXES
  110 J=0
      K=0
  111 IF(X-XFNC(I,IX,1)) 120,120,125
  120 IF(J.EQ.0) GO TO 121
      IX=IX-1
      GO TO 1065
  121 K=1
      IX=IX-1
      IF(IX.NE.0) GO TO 111
      IX=1
      GO TO 1065
  125 IF(K.EQ.1) GO TO 1065
      J=1
      IX=IX+1
      GO TO 111
C  SET INDEXES FOR INTERPOLATION
  150 IF(IX.LT.1) IX=1
      J=J4-J5+1
      IF(IX.GT.J) IX=J
      L=IX+J5-1
C  MAKE INTERPOLATION
      Y=0.
      DO 400 K=IX,L
      YL=1.0
```

```
      DO 500 J=1X,L
      IF(J.EQ.K) GO TO 500
      XJ=XFNC(1,J,1)
      YL=YL*(X-XJ)/(XFNC(1,K,1)-XJ)
  500 CONTINUE
  400 Y=Y+YL*XFNC(1,K,2)
      RETURN
      END
```

```
 SUBROUTINE DUPDAT
 COMMON /OIL/XFNC(5,10,2),IFNC(5,5),IERROR,NW,S1,S2,S3,
1S4,S5,A1,A2,A3,A4,A5,F1,F2,F3,F4,E1,D1,D2,D3,D4,IY,
2WYOMING,CANADA,RWYO,RCAN
 S1=S1+D1
 S2=S2+D2
 S3=S3+D3
 S4=S4-D4
 S5=S5+D4
 RETURN
 END
```

```
      SUBROUTINE GAS (DEMAND,STOCK,INCRE,AHOLD,BC,ZC
     1,KODSEN,IC,IR,KODE,CJ,OBJ,NNNC,HOLDS)
      DIMENSION AHOLD(10,20),BC(20),ZC(20),KODSEN(20)
     1,CJ(20),HOLDS(25,6)
      COMMON/CMAIN/IDATE,IWRIR
      DIMENSION BASIS(10)
      STOCK=DEMAND
      DEMAND=DEMAND/1.0E6
      NC=4*IC
      NR=2*IR
      DO 1003 I=1,IR
      BC(I)=HOLDS(INCRE,I)
1003  CONTINUE
      OBJ=0.0
      DO 222 I=1,10
      BASIS(I)=0.0
222   CONTINUE
      BC(6)=DEMAND
      IF(IWRIR.EQ.0)GO TO 201
      WRITE(12,1004)IDATE
 201  CONTINUE
      CALL SIMPLEX(AHOLD,BC,ZC,KODSEN,IC,IR,CJ,NNNC,KODE,OBJ,
     1BASIS,IWRIR,NR,NC)
      IF(BASIS(5).GT.0)GO TO 1111
      GO TO 1110
1111  KODSEN(2)=5
1110  CONTINUE
      DO 500 I=1,IR
      CJ(I)=CJ(I)*1.06
 500  CONTINUE
      IF(IWRIR.EQ.0)GO TO 2003
      PRICE=OBJ/DEMAND
      WRITE(12,1005)PRICE
      WRITE(12,1006)
      WRITE(12,1007)(BASIS(I),I=1,NNNC)
1004  FORMAT(1H1,//,20(1H*),5X,'GAS SUPPLY',5X,I5,5X,20(1H*),//)
1005  FORMAT(10X,'AVERAGE PRICE PER MCF',5X,E15.5,//)
1006  FORMAT(10X,'SOURCES OF GAS SUPPLY',//)
1007  FORMAT(10X,'MONTANA               ',E15.5,/,
     1 10X,'CANADA                ',E15.5,/,
     2 10X,'WYOMING               ',E15.5,/,
     3 10X,'ARTIC                 ',E15.5,/,
     4 10X,'COAL GAS              ',E15.5)
 2003 RETURN
      END
```

```
      SUBROUTINE SIMPLEX (A,B,ZC,KODSEN,IC,IR,CJ,NNNC,KODE
     1,OBJ,BASIS,IWRTR,NR,NC)
C       ***************************************************
C       A SIMPLEX ALGORITHM TO SOLVE FOR ZMAX OR ZMIN
C       PERMITS UP TO TWENTY(20) STRUCTURAL VARIABLES AND
C       TWENTY CONSTRAINT EQUATIONS
C       ***************************************************
C       VARIABLE DEFINITIONS
C       KODSEN(I)= THE DIRECTION OF THE INEQUALITIES OR THE
C               PRESENCE OF AN EQUALITY.
C               1 = GE
C               2 = LE
C               3 = EQ
C       A(I,J) = THE COEFFICIENTS OF THE CONSTRAINT EQUATIONS
C       KODE = THE TYPE OF PROBLEM TO BE SOLVED
C               0 = ZMAX
C               1 = ZMIN
C       B(I) = THE CONSTANTS FOR THE CONSTRAINT EQUATIONS
C       IC = THE NUMBER OF STRUCTURAL VARIABLES
C       IR = THE NUMBER OF CONSTRAINT EQUATIONS
C       ZC(I) = THE VALUE OF THE VARIABLE IN THE DUAL
C       NNNC=THE NUMBER OF NON-ZERO CONSTRAINTS
C       BASIS=A VECTOR WHICH RETURNS THE VARIABLES IN THE BASIS
C       OBJ=A VARIABLE WHICH RETURNS THE ZMAX OR ZMIN
C       CJ(I) = THE OBJECTIVE FUNCTION IN A VECTOR
C       IWRTR IS A VARIABLE GOVERNING OUTPUT
C               0=NO OUTPUT IS PRINTED,DATA RETURNED TO MAIN
C               1=FINAL SOLUTION PRINTED,DATA RETURNED TO MAIN
C       **********************************************************
      DIMENSION A(10,20),B(10),ZC(20),KODSEN(20),CJ(20),BASIS(10)
      DIMENSION JART1(40),COEF(40),NXI(75),NXJ(75),ISUBC(60)
     1,CI(40),Z(75)
        CALL OPEN(12,'@LPT',2,IER)
C       **********************************************
C       THESE OPTIONALLY COMPILED LINES ALLOW THE USER TO
C       CHECK THE INPUT DATA
C       **********************************************
X       TYPE IC,IR,NNNC
X       TYPE KODE,IWRTR,OBJ
X       TYPE 'CJ   ',(CJ(I),I=1,NNNC)
X       TYPE 'BASIS    ',(BASIS(I),I=1,NNNC)
X       TYPE 'KODSEN    ',(KODSEN(I),I=1,IR)
X       TYPE 'CONSTANTS  ',(B(I),I=1,IR)
X       TYPE 'ZC    ',(ZC(I),I=1,10)
X       PAUSE
X       DO 1 I=1,IR
X1      TYPE (A(I,J),J=1,IC)
C       *************************************************
C       END OF DATA TEST BLOCK
C       *************************************************
        DO 2009 ICK=1,NNNC
        NXJ(ICK)=ICK
2009  CONTINUE
```

```
C
C       THIS TAKES CARE OF A(I,J)VALUES THAT ARE NOT READ IN
C
        ILL=0
C
        DO 1000 I=1,IR
        ILL=ILL+1
        LNM=ILL+IC
        IF(KODSEN(I)-2) 1001,1002,1007
C
C       COMES HERE WHEN CONSTRAINT (I) IS OF THE LE TYPE
C
 1002   A(I,LNM)=1.0
        NXI(I)=LNM
        NXJ(LNM)=LNM
        CJ(LNM)=0.0
        GO TO 1000
C
C       COMES HERE WHEN CONSTRAINT IS OF GE TYPE
C
 1001   A(I,LNM)=-1.0
        CJ(LNM)=0.0
        NXJ(LNM)=LNM
        ILL=ILL+1
        LNM=ILL+IC
        A(I,LNM)=1.0
        NXI(I)=LNM
        NXJ(LNM)=LNM
        JART1(I)=LNM
 1010   IF(KODE) 1005,1005,1006
C
C       IF KODE=0 IT MEANS TO MAXIMIZE IN WHICH
C       CASE WE MAKE ARTIFICAL CJ VERY NEGATIVE
C
1005    CJ(LNM)=-10.E12
        GO TO 1000
1006    CJ(LNM)=10.E12
        GO TO 1000
C
C       COMES HERE WHEN AN EQ CONSTRAINT TYPE IS READ
C
 1007   A(I,LNM)=1.0
        NXI(I)=LNM
        NXJ(LNM)=LNM
        JART1(I)=LNM
        GO TO 1010
 1000   CONTINUE
C
        M=IR
        N=LNM
        K=0
C
C       SETUP E1.
```

```
C
      DO 15 I=1,M
      DO 15 J=1,N
      IF (NXI(I)-NXJ(J)) 15,14,15
   14 CI(I) = CJ(J)
   15 CONTINUE
C
      ITER=0
C
C     COMPUTE Z AND ZC.
C
  21  DO 25 J=1,N
      Z(J) = 0.0
      DO 24 I=1,M
      Z(J) = Z(J)+CI(I)*A(I,J)
  24   CONTINUE
      ZC(J) = Z(J)-CJ(J)
  25   CONTINUE
C
      OBJ = 0.0
      DO 28 I=1,M
      OBJ = OBJ+CI(I)*B(I)
 28    CONTINUE
C
C     DETERMINE PIVOT COLUMN.
C
      ZCM = ZC(1)
      JM = 1
C
      DO 109 J=2,N
      IF (KODE) 106,105,106
  105 IF (ZC(J)-ZCM) 107,109,109
  106 IF (ZC(J)-ZCM) 109,109,107
  107 ZCM = ZC(J)
      JM = J
  109 CONTINUE
C
C     CHECK FOR OPTIMAL.
C
      IF (KODE) 122,121,122
  121 IF(ZCM)151,2222,2222
  122 IF(ZCM)2222,2222,151
       GO TO 2222
C
C     DETERMINE PIVOT ROW.
C
  151 XM=1.0E10
      IM=0
C
      DO 159 I=1,M
      IF (A(I,JM)) 159,159,155
  155 XX = B(I)/A(I,JM)
      IF (XX-XM) 157,159,159
```

```
  157   XM = XX
        IM = I
  159   CONTINUE
C
C       PERFORM PIVOT OPERATION.
C
        XX = A(IM,JM)
        B(IM) = B(IM)/XX
C
        DO 154 J=1,N
  154   A(IM,J) = A(IM,J)/XX
C
        DO 161 I=1,M
        IF (I-IM) 157,161,157
  157   XX = A(I,JM)
        B(I) = B(I)-XX*B(IM)
        DO 160 J=1,N
        A(I,J) = A(I,J)-XX*A(IM,J)
 160     CONTINUE
C
C
  161   CONTINUE
        CI(IM) = CJ(JM)
        NXI(IM) = NXJ(JM)
        GO TO 21
 2222   IF (IWRIR.EQ.0)GO TO 2888
        WRITE (12,2225)
 2225   FORMAT(10X,14HFINAL SOLUTION//)
        WRITE (12,2224)OBJ
 2224   FORMAT(10X,4HZ = ,E15.5//)
 2888   DO 2250 I=1,IC
C
        DO 2251 J=1,M
        IF(I-NXI(J))2251,2255,2251
 2251   CONTINUE
C
        XPR=0.0
        GO TO 2256
 2255   XPR=B(J)
 2256   IF(IWRIR.EQ.0)GO TO 2257
        WRITE(12,2233)I,XPR
 2257   BASIS(I)=XPR
 2250   CONTINUE
         IF (IWRIR.EQ.0)GO TO 201
 2233   FORMAT(10X,1HX,I2,2H= ,F15.5/)
        WRITE(12,2234)
 2234   FORMAT(//10X,24HOTHER VARIABLES IN BASIS//)
        IC = IC+1
C
        DO 2240 I=1,M
        DO 2240 J=IC,LNM
        IF(J-NXI(I))2240,2241,2240
 2241   WRITE(12,2233)J,B(I)
```

```
 2240   CONTINUE
C
        WRITE(12,2250)
 2250   FORMAT(//10X,13HSHADOW PRICES//)
C
        DO 2260 I=1,LNM
        DO 2262 J=1,M
        IF(I-NX1(J))2262,2260,2262
 2262   CONTINUE
        WRITE(12,2255)I,ZC(I)
 2260   CONTINUE
         IC=IC-1
 201    RETURN
        END
```

```
      SUBROUTINE ELECT (DEME,STOCK,AAA,BB,ZZ1,KODER,CCJ
     1,ICOL,IROW,NZER,ICOD,GEN,ZHOLD,FLOW)
      DIMENSION AAA(10,20),BB(10),ZZ1(20),KODER(20),CCJ(20)
     1,ZHOLD(10)
      COMMON /CMAIN/IDATE,IWRIR
      DIMENSION BASOF(10)
      NR=2*IROW
      NC=4*ICOL
      STOCK=DEME
      DEME=DEME/8760.0
      DO 9151 I=1,10
      BB(I)=0.0
      BASOF(I)=0.0
      ZZ1(I)=0.0
9151  CONTINUE
      DO 200 J=1,IROW
      BB(J)=(ZHOLD(J)*DEME)
 200  CONTINUE
      BB(4)=60.0
      BB(5)=340.0
      IF(IWRIR.EQ.0)GO TO 201
      WRITE(12,9110)
 201  CONTINUE
      CALL SIMPLEX (AAA,BB,ZZ1,KODER,ICOL,IROW,CCJ,NZER,ICOD
     1,ZMIN,BASOF,IWRIR,NR,NC)
      IF(IWRIR.EQ.0)GO TO 9150
      COST=ZMIN/DEME
      WRITE(12,9114)COST
      WRITE(12,9111)(BASOF(NM), NM=1,ICOL)
      IF(BASOF(2).GT.GEN)GO TO 9112
      GO TO 9150
9112  WRITE(12,9113)
9110  FORMAT(//,10(1H*),5X,'ELECTRICAL SOURCES',5X,10(1H*),//)
9111  FORMAT(10X,'HYDROELECTRIC',10X,E15.5,5X,'MEGAWATTS',//,
     110X,'COAL ELECTRIC',10X,E15.5,5X,'MEGAWATTS',//,
     210X,'GAS ELECTRIC ',10X,E15.5,5X,'MEGAWATTS',//,
     310X,'OTHER PEAKING',10X,E15.5,5X,'MEGAWATTS',//)
9113  FORMAT(/,10X,'ADDITIONAL GENERATION FACILITIES REQUIRED')
9114  FORMAT(10X,'THE AVERAGE COST PER MEGAWATT(1978 DOLLARS)
     1   ',5X,E15.5,///)
      GEN=GEN+250
      CCJ(2)=CCJ(2)*1.05
9150  RETURN
      END
```

```
      SUBROUTINE DEMOG (EMP)
      COMMON /CCOHORT/AF(17),AM(17),B(8),DF(17),DM(17)
     1,UF(17),UM(17),BR,ALPHA,IP,IM,IF,I3,NB,IB
     2,LFPRM(17),LFPRF(17),SAT,WORK,DUM1,UNEMP
      COMMON/CMAIN/IDATE,IWRTR
      CALL COHORT(EMP)
      WRITE(12,1001)IDATE
      WRITE(12,1002)IP
      WRITE(12,1003)IM
      WRITE(12,1004)IF
      WRITE(12,1005)IB
      WRITE(12,1111)ALPHA
      WRITE (12,1011)WORK
      X=0
      Y=0
      WRITE(12,1020)
      DO 500 J=1,16
      X=Y
      Y=Y+5
      WRITE(12,1010)X,Y,AM(J),AF(J)
 500  CONTINUE
1001  FORMAT(1H1,////(20X,26HPOPULATION PROJECTIONS FOR
     1,2X,I4)////)
1011  FORMAT((1X,16HTOTAL WORK FORCE,5X,F10.0)//)
1002  FORMAT((1X,19HTOTAL POPULATION IS,5X,F9.0)/)
1003  FORMAT((1X,11HTOTAL MALES,5X,F8.0)/)
1004  FORMAT((1X,13HTOTAL FEMALES,5X,F8.0)/)
1005  FORMAT((1X,12HTOTAL BIRTHS,5X,F8.0)/)
1111  FORMAT((1X,13HNET MIGRATION,5X,F10.0)/)
1010  FORMAT((5X,F3.0,2X,2HTO,2X,F3.0,4X,F8.0,10X,F8.0)/)
1020  FORMAT((5X,3HAGE,12X,5HMALES,10X,7HFEMALES)//)
      RETURN
      END
```

```
        SUBROUTINE COHORT (EMP)
        COMMON /CCOHORT/AF(17),AM(17),B(8),DF(17),DM(17)
     1,OF(17),OM(17),BR,ALPHA,TP,TM,TF,TB,NB,IB
     2,LFPRM(17),LFPRF(17),SAT,WORK,DUM1,UNEMP
C       ********************************************************
C       VARIABLE DEFINITIONS
C       AF=NUMBER OF FEMALES BY AGE
C       AM=NUMBER OF MALES BY AGE
C       B=BIRTH RATE DISTRIBUTION BY AGE
C       BR=BIRTHS EVER PER FEMALE
C       DF=DEATH RATE FOR FEMALES BY AGE
C       DM=DEATH RATE FOR MALES BY AGE
C       OF=FRACTION OF MIGRATION BY FEMALES BY AGE
C       OM=FRACTION OF MIGRATION BY MALES BY AGE
C       TP=TOTAL POPULATION
C       ALPHA=TOTAL MIGRATION
C       TM=TOTAL MALES
C       TF=TOTAL FEMALES
C       TB=TOTAL BIRTHS
C       NB=NUMBER OF FERTILE YEARS
C       IB=AGE BIRTHS START
C       *************************************************
        TF=0
        TM=0
        TB=0
        TP=0
C       ******************************
C       CALCULATE BIRTHS
C       *********************************
        DO 100 N=1,NB
        NN=N+IB-1
        TB=TB+AF(NN)*B(N)*BR
 100    CONTINUE
C       **********************************
C       UPDATE AGE LEVELS
C       *********************************
        DO 200 N=2,16
        NN=18-N
        NK=NN-1
        AF(NN)=AF(NK)*(1.-DF(NK))
        AM(NN)=AM(NK)*(1.-DM(NK))
 200    CONTINUE
        AF(1)=TB/2
        AM(1)=TB/2
C       ******************************************
C       CALCULATE THE WORK FORCE
C       ******************************************
        WORK=0
        DO 600 N=1,15
        WORK=WORK+((AF(N)*LFPRF(N))+(AM(N)*LFPRM(N)))*(.001)
 600    CONTINUE
C       ****************************************************
C       CALCULATE UNEMPLOYMENT AND MIGRATION
```

```
C          ***************************************************
           UNEMP=0
           ALPHA=0
           UNEMP=(WORK-EMP)/WORK
           ALPHA=(UNEMP-SAT)*WORK
C          *************************************
C          ADJUST FOR MIGRATION AND CALCULATE TOTAL POPULATION
C          ************************************
           DO 500 N=1,16
           AF(N)=AF(N)-ALPHA*DF(N)
           AM(N)=AM(N)-ALPHA*DM(N)
           TF=TF+AF(N)
           TM=TM+AM(N)
  500      CONTINUE
           TP=TF+TM
           ALPHA=ALPHA*(-1)
           RETURN
           END
```

SAMPLE OUTPUT FROM THE YEAR 1985*

---

*The "E" notation signifies a power of ten; for every number behind the "E", move the decimal point one place to the right.

```
********************        1985      ********************



        PRODUCTION LEVELS IN THE BASIC SECTOR

        SECTOR         DESIRED OUTPUT          ACTUAL OUTPUT          SHORTFALL


           1           0.14499E   7           0.14499E   7          0.00000E   0

           2           0.28970E   8           0.28970E   8          0.00000E   0

           3           0.36585E   6           0.36585E   6          0.00000E   0

           4           0.48747E   6           0.48747E   6          0.00000E   0

           5           0.11079E   6           0.11079E   6          0.00000E   0

           6           0.19883E   6           0.19883E   6          0.00000E   0

           7           0.16147E   6           0.16147E   6          0.00000E   0

           8           0.73537E   5           0.73537E   5          0.00000E   0

           9           0.37955E   6           0.37955E   6          0.00000E   0

          10           0.44689E   6           0.44689E   6          0.00000E   0

          11           0.41976E   5           0.41976E   5          0.00000E   0

          12           0.51832E   8           0.59637E   8          0.00000E   0

          13           0.19740E   6           0.19740E   6          0.00000E   0

          14           0.15133E   5           0.15133E   5          0.00000E   0
```

```
          ********************     ENERGY DEMANDS     ********************

          ********************     TOTAL DEMAND     ********************

  COAL                   OIL                   GAS                   ELECT                  DIST

0.26216E  6        0.59368E  8        0.61030E  8        0.80203E  7        0.33275E  7

          ********************     BASIC SECTOR     ********************

  COAL                   OIL                   GAS                   ELECT                  DIST

0.14965E  6        0.59366E  8        0.28929E  8        0.50500E  7        0.32708E  7

          ********************     COMMERCIAL SECTOR     ********************

  COAL                   OIL                   GAS                   ELECT                  DIST

0.41198E  5        0.00000E  0        0.50383E  7        0.14041E  7        0.49109E  5

          ********************     RESIDENTIAL SECTOR     ********************

  COAL                   OIL                   GAS                   ELECT                  DIST

0.91550E  5        0.00000E  0        0.27065E  8        0.15662E  7        0.76109E  4
```

```
********************   1985   *******************

 ********** STATE VARIABLES ************

SMOOTHED PRODUCTIVITY (BBL/$ SPENT)              4.57903

SMOOTHED DISCOVERY MULTIPLIER                  1.38480

NORMAL DRILLING RATE                   26199170.00000

UNDISCOVERED OIL(BBL)                 *1703129000.000

COMMULATIVE DISCOVERED OIL(BBLS)      *1296869000.000


 *********** ANCILLARY VARIABLES ************

RETURN RATIO ($/BBL)/(BBL/$ SPENT)             2.72984

DRILLING RATE ($/YEAR)                         28439490.00000

NORMAL DISCOVERY (BBL/YR)                       5265617.00000

ACTUAL PRODUCTIVITY(BBL DISCOVERED/$)                 0.18515

DISCOVERY RATIO                                      1.00000


 *********** FUNCTIONS *****************

EXPLORATORY DRILLING  $/YEAR VS. RETURN RATIO      26504510.00000

BBL DISCOVERED/$ SPENT VS. COMMULATIVE DISCOVERY             0.18515

DRILLING RATE ADJUSTMENT VS. DISCOVERY MULTIPLIER            1.08551

SIZE OF A MAJOR DISCOVERY (BBL/YEAR)                         0.00000


 ************** EXOGENOUS VARIABLES **************

WELLHEAD PRICE (1976 DOLLARS/BBL)          12.50000


 *************  OTHER  ***************

CRUDE AVAILABLE FOR MONTANA REFINERS          0.39456E  8
```

```
********************      GAS SUPPLY      1985      *********************

         FINAL SOLUTION

         Z =       0.16858E  3


         X 1=       0.35000E  2

         X 2=       0.25500E  2

         X 3=       0.53001E  0

         X 4=       0.00000E  0

         X 5=       0.00000E  0


         OTHER VARIABLES IN BASIS

         X 6=       0.70000E  1

         X 7=       0.00000E  0

         X 9=       0.24470E  2


         SHADOW PRICES

         X 4=      -0.44216E  1

         X 5=      -0.40008E  1

         X 8=      -0.45772E  2

         X10=      -0.10000E 14

         X11=      -0.29280E  1

         X12=      -0.10000E 14
        AVERAGE PRICE PER MCF              0.30899E  1

         SOURCES OF GAS SUPPLY

         MONTANA                    0.35000E  2
         CANADA                     0.25500E  2
         WYOMING                    0.53001E  0
         ARTIC                      0.00000E  0
         COAL GAS                   0.00000E  0

*********      ELECTRICAL SOURCES      **********
```

```
FINAL SOLUTION

Z =      0.31363E  5

X  1=      0.34000E  3

X  2=      0.91006E  3

X  3=      0.60000E  2

X  4=      0.55112E  2


OTHER VARIABLES IN BASIS

X  5=      0.34761E  3


SHADOW PRICES

X  6=     -0.10000E 14

X  7=     -0.32187E  2

X  8=     -0.10000E 14

X  9=     -0.41606E  2

X10=     -0.10000E 14

X11=     -0.62476E  3

X12=     -0.10000E 14

THE AVERAGE COST PER MEGAWATT(1976 DOLLARS)          0.34255E  2


HYDROELECTRIC                    0.34000E  3      MEGAWATTS

COAL ELECTRIC                    0.91006E  3      MEGAWATTS

GAS ELECTRIC                     0.60000E  2      MEGAWATTS

OTHER PEAKING                    0.55112E  2      MEGAWATTS
```

```
                    POPULATION PROJECTIONS FOR  1985


TOTAL POPULATION IS        899266.

TOTAL MALES       431911.

TOTAL FEMALES       467354.

TOTAL BIRTHS       71500.

NET MIGRATION           2650.

TOTAL WORK FORCE          594162.


   AGE                  MALES              FEMALES


    0.   TO    5.        35685.               35670.

    5.   TO   10.        34541.               34471.

   10.   TO   15.        32180.               32481.

   15.   TO   20.        31184.               31516.

   20.   TO   25.        31680.               32118.

   25.   TO   30.        32503.               33250.

   30.   TO   35.        32526.               33626.

   35.   TO   40.        30763.               32118.

   40.   TO   45.        27712.               29189.

   45.   TO   50.        25571.               27159.

   50.   TO   55.        25424.               27572.

   55.   TO   60.        26733.               29812.

   60.   TO   65.        25004.               29501.

   65.   TO   70.        20429.               26225.

   70.   TO   75.        12271.               18377.

   75.   TO   80.         7705.               14090.
```